Psychological and Physiological Factors that Affect Success in Ultra-marathoners

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Contents

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CHAPTER ONE

1. General Introduction

1.1. Introduction

Despite falling levels of societal physical activity, and increased obesity in the general population, a small, but growing number of individuals compete around the world, in the physically and mentally demanding sport of ultra-marathons (Holt, Lee, Kim, & Klein, 2014; Hurdiel et al., 2018; Wardenaar et al., 2018). Such long-distance running events frequently take place in challenging environments, far in excess of the standard marathon distance of 42.20 km, over fixed distances, including 50 km, and 100 km, or time-limited, over multiple days (Knechtle, 2015).

Whilst modern athletes, including the very best ultra-marathoners, are potentially homogeneous physically and technically, it is possible that the maintenance of successful performance under pressure is driven by psychological attributes (Cowden, 2016, 2017). Much of the current sports psychology literature pays particular attention to mental toughness, motivation and personality. Indeed, research linked to mental toughness suggests that the mentally tough individual is marked by perseverance in the face of adversity, and an improved understanding of the construct may benefit the endurance athlete by facilitating: (a) effective management of challenges encountered; (b) improved problem-coping skills; and (c) an increased focus on individual goals (Gucciardi, Peeling, Ducker & Dawson, 2016; Perry, Clough, Crust, Earle & Nicholls, 2013). Despite concerns regarding a lack of agreement in defining mental toughness as a psychological construct it continues to be seen as crucial to the success of athletes, and receives considerable research focus (Andersen, 2013; Gucciardi, 2017; Marshall et al., 2017; Vaughan, Carter, Cockroft, & Maggiorini, 2018). Running ultra-marathons necessitates significant motivation to dedicate extended periods of time to complete long periods of running, in training and competition, whilst balancing commitments to work, family and friends (Krouse, Ransdell, Lucas, & Pritchard, 2011; Zach et al., 2018). In addition, certain personality types may also impact the ability to handle stress in the absence of a decline in performance and are largely attributable to genetic and non-shared environmental factors (Horsburgh, Schermer, Veselka, & Vernon, 2009; Kaiseler, Polman, & Nicholls, 2012).

A growing body of literature has therefore explored the impact of the human genome on phenotypes that underpin endurance performance, including musculature, maximum oxygen uptake, and running economy (Barnes & Kilding, 2014; Sarzynski, Ghosh, & Bouchard, 2017; Valdivieso et al., 2017). Consequently, selective genomic analysis of ultra-marathoners may provide an insight into the factors that define the endurance athlete.

Relatively little quantitative, interdisciplinary research has been directed at both psychological and physiological factors, and their interaction, that predict performance in ultra-marathoners, or what drives ultra-marathoners to push their individual limits (Wortley & Islas, 2011). Indeed, despite research yielding an improved understanding of the factors involved in endurance performance, the bulk of studies have been specialised and fragmented, focusing on individual elements of psychology, physiology, biomechanics, and/or genetics (Balagué, Torrents, Hristovski, & Kelso, 2017; Hristovski, 2013). Recently it has been suggested that the introduction of a more dynamic approach to research, modelling, and integrating seemingly disparate disciplines, including psychology and physiology, may benefit sport and exercise science, as it has in other research fields (Balagué et al., 2017). Indeed, cognitive science has had considerable success over the last two decades, utilising knowledge and expertise from diverse and discrete fields of study, including neuroscience, neurobiology, psychology, linguistics and computing, to tackle diverse challenges including modelling memory, language, visual perception, problem solving, and attention (Baddeley, 2012; Eysenck & Keane, 2015; Wan, Chen, Shi, & Zhou, 2018). A more comprehensive exploration of measures including mental toughness, personality, motivation, physiological stress, perception of effort, genetic predispositions, and aerobic fitness may enable sports professionals to provide improved support to ultra-marathoners.

At present, an understanding of endurance, synthesising both psychological and physiological factors, remains elusive, possibly as a result of associated research challenges, including cost, resources and available expertise. However, some limited, interdisciplinary research success has already led to an integrated view of fatigue, and the speculation that the termination of aerobic sessions, and endurance performance overall, is likely to be a product of the interaction of multiple psychological and physiological variables (Hristovski & Balagué, 2010; Inzlicht & Marcora, 2016). The Central Governor Model (Noakes, 2007), and the Psychobiological model (Marcora, 2008), have both challenged the pre-existing view that the length of aerobic exercise is determined by muscle fatigue, and suggested a close relationship with perception of effort (Crewe, Tucker, & Noakes, 2008; Inzlicht & Marcora, 2016).

The aim of the present research is to provide an integrated understanding of the factors involved in endurance through the quantification of the psychological, and physiological factors that: (a) identify, and affect success in, the ultra-marathoner, and (b) affect the limits of aerobic fitness. Other supplementary aims include, challenging existing psychological models of mental toughness, motivation and personality to successfully identify ultra-marathoners, and provide support for integrating measures from both psychology and physiology, to produce a novel, interdisciplinary Optimum Balanced Performance Model of Endurance Success in ultra-marathons.

1.2. Experimental Aims and Objectives

The principal aim of this thesis was to adopt an interdisciplinary, quantitative research methodology to identify and measure the psychological and physiological factors that affect success in ultra-marathoners. The primary objectives in each study were as follows:

Study 1: To use an interdisciplinary approach to quantify, and compare both psychological factors, including mental toughness and personality, and physiological factors, including $\dot{V}O_{2peak}$ scores, and the ACE gene allele that may predict endurance performance between ultra-marathoners and non-ultra-marathoners.

Study 2: To use an interdisciplinary approach to quantify, and compare: (a) psychological factors, including mental toughness, personality and motivation; and (b) physiological factors, including $\dot{V}O_{2peak}$ scores, pain tolerance and threshold, stress hormone, lactate threshold, running economy, and the 5HTT, BDNF, D4DR genes that may predict endurance performance as a result of further delineation between ultra-marathon, aerobic and low aerobic groups.

Study 3: To use an interdisciplinary approach to quantify psychological factors, including mental toughness, personality and motivation, and physiological factors, including stress hormones in ultra-marathoners participating in a single event and contribute to knowledge by identifying those measures that predict successful endurance race performance.

1.3. Overview of Thesis

This thesis is presented in 7 chapters, a brief summary of each is described below:

Chapter 2:

A review of the literature critically examined the existing research pertaining to psychological and physiological factors that underpin human endurance performance in ultra-marathoners, and models that attempt their integration.

Chapter 3:

This chapter included the experimental design and methodology adopted in the four separate studies. A description of the psychological, physiological testing and statistical data analysis procedures, in addition to biochemical analysis, is provided.

Chapter 4:

Study 1 adopted an interdisciplinary approach to quantify and compare both psychological models, including mental toughness and personality, and physiological factors including $\dot{V}O_{2peak}$ scores, and the ACE gene allele, between ultra-marathoners and non-ultra-marathoners.

Chapter 5:

Study 2 was designed to extend the interdisciplinary approach in Study 1 by quantifying and comparing an increased range of psychophysiological measures, including motivation, pain tolerance and threshold, stress hormones, lactate threshold, running economy, and the 5HTT, BDNF, D4DR genes, between ultra-marathoners, aerobic and low aerobic groups as defined by ultra-marathon participation and volume of aerobic training.

Chapter 6:

Study 3 was designed to quantify, and integrate, psychological models, including mental toughness, personality and motivation, and physiological factors including stress hormone, in ultra-marathoners participating in a single race and extend the body of scientific knowledge by identifying those measures that predict successful performance.

Chapter 7:

The general discussion included a summary of findings, theoretical implications, and design limitations of the four studies. Findings from all four studies were interpreted collectively to propose a new interdisciplinary model of human endurance, and finally, a discussion of recommendations for future research was provided.

CHAPTER TWO

2. Literature Review

2.1. Introduction

A narrative review of the extant research literature, identifying both psychological and physiological factors involved in successful aerobic endurance was conducted, where success is defined as the participation in, and completion of, an ultra-marathon event (Fonseca-Engelhardt et al., 2013). The aims were to: (a) highlight key psychological and physiological studies; (b) identify pertinent psychological models; (c) identify gaps in the academic understanding, explanations and methodological approaches; (d) describe interdisciplinary models proposed to explain aerobic fatigue; and finally (e) introduce the focus of this programme of interdisciplinary research and how each study is designed to contribute to the existing body of literature.

2.1.1. Defining Human Endurance

In recent years, considerable growth has been seen in the number of participants entering endurance events, with more than one hundred thousand athletes worldwide challenging the limits of their performance (Hurdiel et al., 2018; Simpson, Post, Young, & Jensen, 2014; Wardenaar et al., 2018;). Ultra-marathons typically have a duration in excess of 6 hours, and are frequently standard distances of 50km, and 100km, but also include much longer, multi-day races, taking place over difficult terrains, with significant ascents and descents (Knechtle, 2015).

Human endurance is defined as an individual's capacity to sustain a given energy expenditure for the longest time possible, with races, such as ultra-marathons, requiring considerable physical and mental effort, and the need to overcome feelings of exertional discomfort (Billat, Koralsztein, & Morton, 1999; Brick, MacIntyre & Campbell, 2014; Hurdiel et al., 2018). Athletes frequently undertake physiological testing to better understand, and improve, endurance performance, and tailor their training, nutrition and recovery, based on the results (Seiler, Katch, Hopkins, & Buchheit, 2011; Wardenaar et al., 2018). Endurance, as with all human behaviour, has a psychological element and researchers have identified that psychological factors, including interventions, such as goal setting and self-talk, and mental fatigue, affect performance (Mccormick, Meijen, & Marcora, 2015). The findings of muscular endurance training by Crust and Clough (2005) indicated mental toughness as having an influence on endurance performance, with the potential to reduce, or remove, the perception of pain. More recently, researchers speculated that, as a result of the importance of psychological skills during endurance, improved psychological strategies can significantly benefit competitive performance (Inzlicht & Marcora, 2016; McCormick et al., 2015). Conversely, recent research has suggested that running, as an expression of our evolution, may have in turn facilitated brain development, including neurogenesis, the growth and development of nervous tissue (Schulkin, 2016).

2.1.2. Evolutionary Definition of Endurance

Based on evidence from evolutionary biology, physiology, and anthropology, it has been hypothesised that endurance running historically is important in the pursuit of prey, with key physiological adaptions evolving over millions of years to benefit long distance running, from early hominins through to modern homo sapiens (Brooks, 2012; Hawley, Hargreaves, Joyner, & Zierath, 2014; Schulkin, 2016). Bramble and Lieberman (2004), postulate that homo sapiens are, as a species, designed for endurance, with highly developed, specialised features that may have provided a significant contribution to the evolution of the human form.

Human endurance capacity is comparable, and often exceeds, that of other mammals, with key evolutionary, ancestral adaptations including, upright, bipedal locomotion, a tall, narrow physique, long legs and a developed achilles tendon providing energy return, and efficient heat loss, necessary to facilitate life as a hunter-gatherer (Bramble & Lieberman, 2004). Whilst a moderately trained runner can easily complete 10 km, and with training, a half, or full marathon, other primates are fairly sedentary; even fast quadrupeds, including horses, have been beaten by well-trained runners over longer running distances (Bramble & Lieberman, 2004; Brooks, 2012). It has been suggested that increased locomotor efficiency, along with the ability to obtain, store, and utilise energy, may have enabled early humans to persistence hunt, running prey to exhaustion and collapse, to meet metabolic costs of a larger brain (Brooks, 2012; Pontzer et al., 2016).

2.1.3. Interdisciplinary Approach to Endurance Research

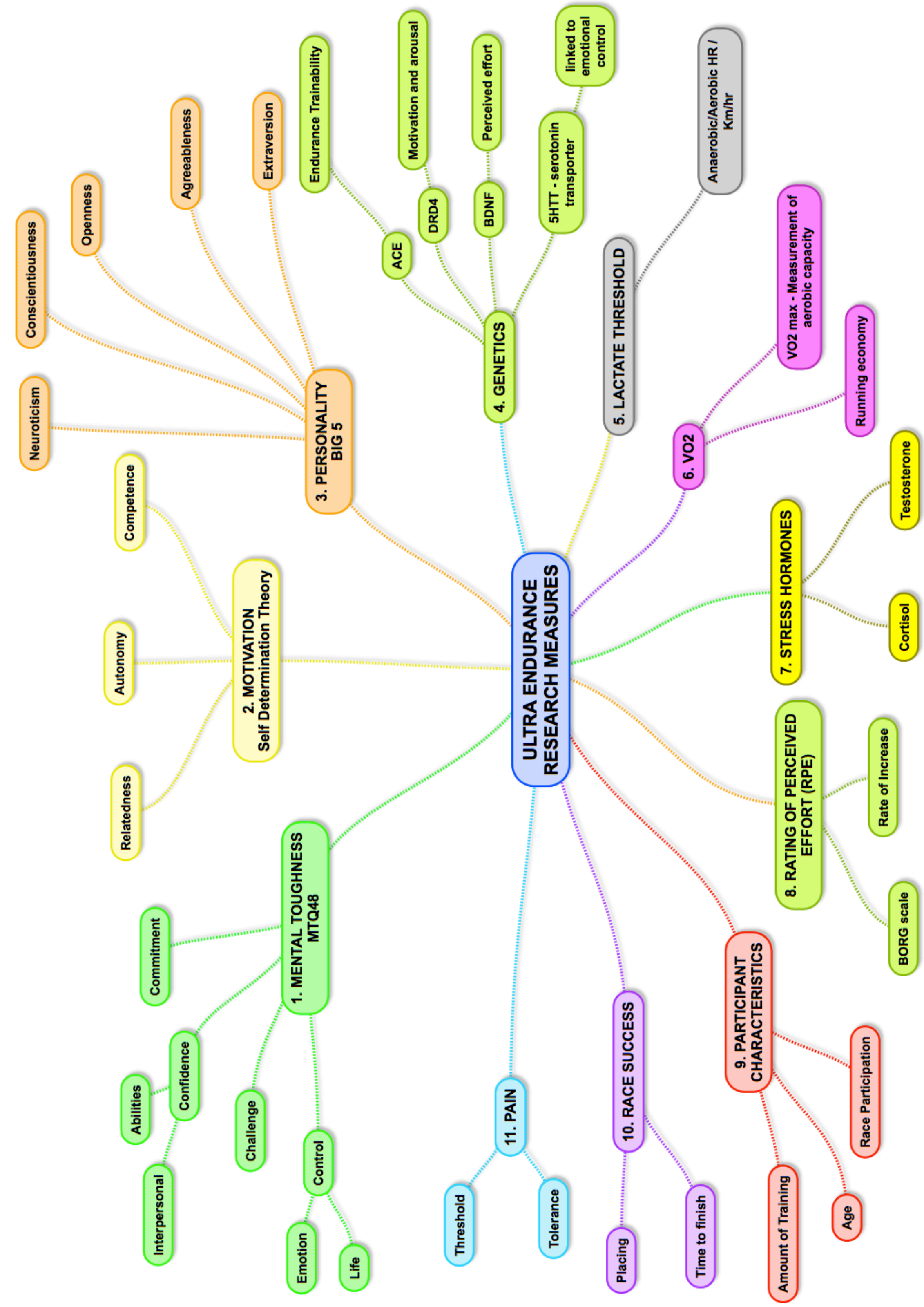
Comparatively recently, in evolutionary terms, our endurance potential tends to be visible in athletic performance. In addition to the rapid rise in the number of ultra-marathon events being planned, and the number of successful participants, there has been an increase in the amount of research conducted on participation profiles and performance in ultra-marathoners (Fonseca-Engelhardt et al., 2013; Hoffman, Ong & Wang, 2010).

Also, recently it has been speculated that major gains are likely to be identified from an interdisciplinary approach to sport and exercise science, rather than fragmented, contextually isolated research (Balagué et al., 2017). It has been theorised that, in living organisms, components cannot be analysed out of context, and may indeed behave differently when viewed in isolation rather than part of a network (Hristovski, 2013). Contextual isolation, and a failure to integrate knowledge from a number of disciplines may result in an insufficient understanding of sport-related phenomena, whilst an interdisciplinary approach may offer more valuable and informed directions (Balagué et al., 2017). As with successes in cognitive science in recent decades, a cross-discipline, and interdisciplinary, approach has seen significant success in research and model development in disciplines as diverse as language emergence, natural language processing, working memory and mental imagery (Baddeley, 2012; Gong, Shuai, & Comrie, 2014; Moran, Guillot, Macintyre, & Collet, 2011; Wan et al., 2018).

The remainder of this chapter describes research into psychological models and physiological studies, including related measures that affect performance in ultra-marathoners, before exploring, in Section 2.4, interdisciplinary, psychophysiological models proposed to explain fatigue, and the cessation of aerobic activities. Figure 2.1 identifies the factors reviewed, and quantified, and are numbered as follows: 1-3, psychological; 4-7 physiological; and 8-11 interdisciplinary measures.

Figure 2.1.

Quantitative Measures of Endurance Performance



2.2. Psychological Approach to Endurance

A better understanding of the psychological factors that elevate endurance performance will lead to improved evidence-based, practical and psychological intervention for athletes (McCormick et al., 2015). According to recent research, during sporting competition an athletes' behavioural responses rely on various psychological factors, including mental toughness, and its role is pivotal in supporting adaptive responses to pressure (Cowden, 2016, 2017).

2.2.1. Mental Toughness

This section provides an overview of the background, key concepts and theories, and salient research findings, regarding the concept of mental toughness and explores its capacity to influence endurance performance.

2.2.1.1. Definition of Mental Toughness and Theoretical Background

Mental toughness has been widely recognised, in both training and competition, by coaches and athletes, as an important, multidimensional, psychological construct related to performance enhancement in sport (Gucciardi et al., 2016; Perry et al., 2013; Vaughan, Hanna, & Breslin, 2018). Researchers have suggested that mental toughness provides a potential advantage over opponents by enabling individuals to cope better with the demands that sport places on them, whilst maintaining consistency in determination, focus, and the perception of being in control under competitive pressure (Jones, Hanton, & Connaughton, 2002). Research has attempted to define mental toughness, along with its constituent parts, to better understand the impact the construct has on how athletes respond to stress, to facilitate their development, and to define appropriate instruments for measurement.

Much of the early research, conducted to clearly define the concept of mental toughness, relied heavily on the theoretical understanding of the related concepts of resilience (Rutter, 1985; 2012), and hardiness (Kobasa, 1979).

2.2.1.2.Early Concepts of Mental Toughness

Resilience

Resilience has been described as an individual's ability to bounce back from life's challenges and unforeseen difficulties, providing mental protection from emotional and mental disorders (Rutter, 1985; 2012). The construct is defined as a reduced vulnerability to environmental risk, and stress, a protective effect enabling individuals to maintain their functioning, and is often linked to the emergence of positive psychology (Fletcher & Sarkar, 2016; Rutter, 2012; Seligman & Csikszentmihalyi, 2000). According to Jackson and Watkin (2004), it is not the experience of hard times that determines whether we succeed or fail, but how we respond, with the resilient individual having an internal drive, and flexible thinking, to confront new challenges and an ability to focus on that which is within their control. Resilience is identified with an improved outcome for individuals from similarly adverse backgrounds or experiencing comparable, challenging experiences. An exposure to stress may have the beneficial effect of increased resistance to similar stressors (Rutter, 2012). According to Fletcher and Sarkar (2016), a lack of resilience should not be confused with weakness, as such vulnerability to challenges may allow resilience to develop, as required for high performance. Furthermore, mental fortitude training, underpinned by resilience-related theory, has been shown to enhance resilience and the ability to thrive under pressure (Fletcher & Sarkar, 2016). Resilience training interventions have shown positive results in both the workplace (Robertson, Cooper, Sarkar, & Curran, 2015; Vanhove, Herian, Perez, Harms, & Lester, 2016), and in sport (Bryan, O'Shea, & Macintyre, 2017), and may benefit, not only in dealing with stress and anxiety, post-traumatic growth (Rendon, 2015), but also as an enabler for greater accomplishments. A recent systematic review identified a lack of clarity, and agreement, regarding the conceptualisation of resilience (Bryan, O'Shea, & Macintyre, 2017). In answer, Bryan et al. (2017) proposed that resilience is a dynamic ability to maintain functioning in response to challenges through facilitative adaptations, involving metacognition processes, including reflecting on mistakes.

Hardiness

Hardiness has its conceptual roots in health psychology, with researchers particularly focused on the relationship between stress and illness, and the impact of personality in recovering from illness. An individual high in hardiness recognises there is a choice regarding handling externally triggered events by maintaining an internal locus of control (Kobasa, 1979). Subsequent research, though correlational and restricted to adult students at a US defence college, has identified individuals higher in hardiness as having a more healthy, high density lipoprotein (HDL) cholesterol, and a lower body mass index (BMI), providing protection against cardiovascular disease (Bartone, Valdes, & Sandvik, 2016). Hardiness can buffer an individual against stress, illness, and life events by impacting on an individual's perception of a situation, or event, and subsequently affect behaviour through re-interpretation into something less threatening (Kobasa, Maddi & Kahn, 1982). The resilient person is less likely to avoid the stressor, but instead will become involved, and present, in whatever one does, or encounters. Previous research has established hardiness as a personality trait comprised of three interrelated dimensions: control, a belief that the individual is involved, rather than helpless, in life's outcomes; challenge, an acceptance that change is normal and provides opportunity; and commitment, implies activity, and involvement, rather than passivity and avoidance (Kobasa et al., 1982). Research by Kobasa et al. (1982, 1985), observed that business executives identified with increased levels of hardiness, had a reduced occurrence of illness resulting from stress.

2.2.1.3.Researching the Construct Mental Toughness

Since 2002, a key focus, mostly derived from qualitative research with elite athletes, has been to remove the ambiguity around mental toughness through identification, and definition, of the key characteristics of mental toughness using two distinct approaches (Connaughton, Thelwell & Hanton, 2013). The first approach has been to formulate, through qualitative research methods, including interviewing, a better understanding of mental toughness and its development, and subsequently reduce conceptual ambiguity (Bull, Albinson, & Shambrook, 2005; Gucciardi, Gordon, & Dimmock, 2008; Jones et al., 2002; Jones, Hanton, & Connaughton, 2007; Thelwell, Weston, & Greenlees, 2005). The second approach, using quantitative methods, has involved researchers building upon existing psychological theories, from non-sporting areas, including health psychology, to develop measures, and models, to investigate mental toughness (Clough, Earle, & Sewell, 2002; Crust & Clough, 2005; Crust 2007, 2008, 2008a).

Though the aim in this thesis is to quantitatively measure both psychological and physiological factors - and compare between measures, participants, and multiple time points - a review of the qualitative methodology is warranted for several reasons. Qualitative designs, including unstructured, or semi-structured techniques have provided important insights into, and informed the early development of, mental toughness, and provided definitions for quantitative research (Anthony, Gucciardi, & Gordon, 2016). However, despite prior success, concerns have been raised regarding qualitative methods, including: (a) a reliance on the analysis of self-report questionnaires rather than scientific investigation; (b) a failure to provide ongoing advancement in the conceptual understanding of the development of mental toughness; and (c) an inability to generalise much of the published qualitative research due to the focus on elite athletes (Gucciardi, 2017; Connaughton et al., 2013; Gucciardi et al., 2014).

Characteristics of Mentally Tough Performers

Researchers initially attempted to qualitatively define mental toughness and identify its key characteristics through interviewing athletes and their coaches (Bull et al., 2005; Gucciardi et al., 2008; Jones et al., 2002; 2007; Thelwell et al., 2005). One of the most cited of these studies, was by Jones et al. (2002), who sampled athletes, from both individual and team sports, that had previously represented their country in major events, including the Olympics. Participants took part in focus groups to identify personal constructs in relation to mental toughness and individual interviews were subsequently held to confirm and rank the mental toughness attributes identified. Jones et al.'s (2002) research, and accompanying analysis, defined mental toughness as being both natural and developed, providing an advantage over opponents through an improved ability to cope with the demands of training, competition and lifestyle, whilst remaining more consistent, attention focussed and controlled under pressure.

A list of 12 ranked attributes were proposed to develop mental toughness, including, a steadfast belief in the ability to achieve goals, a very strong motivation to succeed whilst maintaining focus despite distractions, a disregard of other athletes' performances, and an ability to excel under the pressure of competition (Jones et al., 2002). A subsequent study interviewed super elite athletes, coaches, and psychologists, from multiple sporting backgrounds, to further conceptualise mental toughness (Jones et al., 2007). The earlier definition of mental toughness by Jones et al. (2002) was confirmed, whilst the number of listed attributes increased from 12 to 30, clustered into 4 dimensions, including (a) attitude and mindset, (b) training, (c) competition, and (d) post competition.

Research by Jones et al. (2002, 2007) made an important contribution to the existing body of knowledge around mental toughness by providing a comprehensive definition of mental toughness, along with a detailed breakdown of its elements, and identifying it as a cross-discipline psychological construct important to success in sport. However, as with other early studies into mental toughness, there was lack of clarity regarding what mental toughness really is, or how it is developed, and a limited consensus regarding its common conceptual elements (Gucciardi et al., 2014). Criticisms have also been raised regarding small sample sizes, the assumption that athletes and sports professionals interviewed have a clear understanding of mental toughness, and the premise that the perception of mental toughness is homogeneous across sports. As a result of these concerns, and the assumption that elite-athletes are all mentally tough, it is unclear how the definition can be extended to non-elite athletes.

Seven participants from Jones et al. (2002) study were re-interviewed regarding the development, and maintenance, of mental toughness (Connaughton, Wadey, Hanton & Jones, 2008). Firstly, the findings indicate that mental toughness developed within three key stages, defined as early, middle, and later years. Secondly, three mechanisms were perceived to assist in the maintenance of mental toughness: a strong desire and internalised motivation for success; an established social support network; and, both basic and advanced mental skills, including focus and concentration (Connaughton et al., 2008). Developing this area further, Connaughton et al. (2010) observed that sports professionals viewed both positive and negative critical experiences, and incidents, as key to the development of mental toughness, and that it, along with maintenance, occurred in a particular dimensional order: attitude and mindset, training, competition, and post-competition. Connaughton et al.'s (2010) findings raise a further question: to what degree can psychological training programs develop mental toughness? Although the present study did not directly explore the development or maintenance of mental toughness in ultra-marathoners, life and sporting experiences, social support, motivation and personality are likely to underpin the decisions and behaviour that have led to success as an endurance athlete.

Single Sport Qualitative Research

Several studies have been conducted to produce a more context-rich understanding of mental toughness and its development in athletes (Bull at al., 2005; Gucciardi, Gordon, Dimmock, 2009; Thelwell et al., 2005). One important study focussed on the development of mental toughness in cricket (Bull et al., 2005). A total of 12 cricketers, rated by their coaches as mentally tough were interviewed; thematic analysis was used to understand the development, maintenance, characteristics and attributes of mental toughness. Five general dimensions, 20 global themes and four structural categories emerged from the data (Bull et al., 2005). The authors concluded mental toughness is comprised of similar attributes to those highlighted by Jones et al. (2002), including self-belief, desire and motivation, along with dealing with pressure and anxiety. The ongoing development and maintenance of mental toughness was strongly influenced by both early environmental factors, including parenting, later exposure to international level sport, and competitor's mind-set (Bull et al., 2005). However, the paper fails to specify the term *mind-set*, or provide clear definition, conceptual clarity or detailed measurement. The results of Bull et al.'s (2005) research has led to improvements in coaching including the involvement of sport psychologists, and an intervention programme to support the development of mental toughness in future cricket generations; this also provides an environment more conducive to winning. Critics have suggested that the research, though built upon established psychological theories has several limitations: (a) the findings were largely descriptive, for example, an exposure to foreign cricket, and the exploitation of learning opportunities, are not obviously quantifiable, and therefore comparable between individuals; (b) it was unclear which global themes related to the development of mental toughness; and (c) there was no explanation of how mental toughness might actually be developed (Gucciardi et al., 2009; Connaughton et al., 2013).

A similar, single-sport, single cohort study by Thelwell et al. (2005), investigated soccer players, and provided further support for the definition of mental toughness provided by Jones et al. (2002). However, analysis of findings suggests one clarification, in that mentally tough athletes always, rather than generally, cope better with both the pressure, and the demands of the sport. Research also ascertained that the environments the player is placed in throughout their early career are essential to the development of mental toughness and may inform methods to teach less experienced players coping strategies. In addition, similar mental toughness attributes were identified in line with the study of Jones et al. (2002), including the need for a resilient, never give in to pressure, character, and a level of self-belief that is undeterred by the challenges associated with competition. The study has a number of limitations worth highlighting, including a small sample size (n = 10), and the sole inclusion of international players, affecting whether the findings can be generalised to other sports, and non-elite athletes. Furthermore, it is questionable whether a person can be mentally tough all the time, leading to the suggestion that mental toughness is a state-like concept; whilst some properties may persist, it may vary across time and situations as a result of changing goals (Gucciardi, 2017).

A further study by Thelwell, Such, Weston, Such, and Greenlees (2010) explored elite gymnasts, to understand the dimensions involved within the development of mental toughness. Analysis of the results demonstrated that mental toughness can be developed through a range of mechanisms and experiences, including mental training, competition, coaching, and engagement with fellow athletes, friends and family. In addition to demonstrating a clear role for psychological skills training in the development of mental toughness, the study indicated, unexpectedly, that the nationality of the gymnast influenced the development of mental toughness, including both cultural and environmental influences (Thelwell et al., 2010). As with previous studies, shortfalls in the study include the assumption that all participating athletes were mentally tough.

Research by Gucciardi et al. (2009) used Personal Construct Psychology (PCP: Kelly, 1955; 1991), to better understand the key attributes of mental toughness in sport. Kelly (1955, 1991) postulated that we anticipate, or predict, events within our world based on personal theories we refine over the period of our lifetime. PCP is based around the idea that whether an individual is troubled, or untroubled, by an event, depends on the meaning that person attaches to it. Consequently, experience, cognition and behaviour are all determined by attempts to anticipate events, or people, and understand the outcome (Gucciardi et al., 2009). A key finding resulting from analysis of interviews with Australian football coaches, using PCP, is that mental toughness was not only observed to be salient for negative situations, or events, such as not being selected, or suffering an injury, but also, for positive situations, or events, such as handling the pressure of being an existing champion, and in good health. This identifies a difference between mental toughness, and resilience and hardiness, both of which according to Gucciardi et al. (2009), fail to encapsulate the concept of positive pressure. And furthermore, that mental toughness may be defined as a collection of emotions and behaviours that enable the athlete to overcome, through perseverance, obstacles, or pressure, and ensure concentration and motivation to achieve goals when things are going well.

The above studies used qualitative methods to explore the development of mental toughness, in individual sports, and assumed that the athletes involved are mentally tough. No research has thus far captured the development, or definition, of mental toughness in non-elite ultra-marathoners. This programme of research will build on the findings of Crust and Clough (2005), described in the next section, and quantitatively measure mental toughness, to compare ultra-marathoners, against non-ultra-marathoners to understand its importance in successful endurance.

2.2.1.4. Measurement of Mental Toughness

Crust and Clough (2005) identified mental toughness as a trait-like dimension of personality, extending the conceptualisation of hardiness (Kobasa et al., 1982) by adding confidence to the three existing concepts of, control, commitment and challenge. Horsburgh et al.'s (2009) research later confirmed that individual differences in mental toughness were indeed largely attributable to genetic and non-shared environmental factors. The four components of the mental toughness model defined by Crust and Clough (2005) are control, commitment, challenge and confidence (4Cs). Their research identified a mentally tough athlete as someone who (a) views negative experiences, or situations as challenges to be overcome, (b) believes they are influential in controlling their future life experiences, (c) remains committed to achieving their goals, and (d) is confident in their abilities to overcome negative life experiences. Mentally tough individuals are likely to be resilient to stress, thrive in competition, have reduced anxiety and be high in self-confidence.

Based on completion of the Mental Toughness 48 Questionnaire (MTQ48) (Crust & Clough, 2005), the authors reported a strong association between mental toughness and physical endurance during a task to hold a dumbbell suspended with a straight arm in front of the body, and speculated that mentally tough participants benefit from a buffering effect that impacts either the attention to, or the perception of, pain. Although, Crust and Clough (2005) invited further investigation of mental toughness in physically demanding situations to better understand physiological correlates some major limitations were apparent in the study. The participants were all students of a similar mean age of 21 years (SD=2.7) and weight 79.6 kg (SD=5.0), and the nature of the task was inherently boring, with no consideration given to previous weight training experience or existing participation in sports that may physically prepare the participant for performing the task. Context may also have an effect, the pressure of producing good results in a tough training session, or more importantly in competition, are more challenging than in a quiet room in a research laboratory. The dumbbell holding task is therefore not ecologically valid or representative of the available endurance activities, including ultra-marathons, and raises doubt on the assumption that mental toughness acts as a buffer during demanding conditions. The divergent validity of the MTQ48 has also been challenged, due to concerns regarding the underlying conceptualisation, failing to report underlying factor analysis, and a lack of independent scrutiny of the underlying factor structure (Sheard, Golby & Wersch, 2009). And finally, the development, and adoption of the MTQ48 appears to lack scientific rigour, with no information supplied regarding an explanation of data collection, and a lack of clear rationale for including the additional concept of confidence on to the pre-existing three concepts of hardiness as proposed originally by Kobasa et al. (1982, 1985). Recent research by Vaughan et al. (2018) has offered support for the scales validity but raises concerns regarding applicability of the MTQ48 to athletes at different competitive levels. Indeed, a study by Gucciardi, Hanton, and Mallett (2012) stated that the four-factor model did not fit the data from their sample of athletes. In response to criticism of the MTQ48, the Sports Mental Toughness Questionnaire (SMTQ) was created to assess confidence, control and constancy, or an unrelenting determination, using 14 items and a 5-point Likert scale (Sheard et al., 2009). However, challenges have also been aimed at the SMTQ, regarding its ability to capture the breadth of mental toughness captured in the earlier qualitative studies, along with distinguishing the key aspects of mental toughness (Gucciardi, Mallett, Hanrahan, & Gordon, 2013a).

2.2.1.5. Critical Appraisal of Mental Toughness

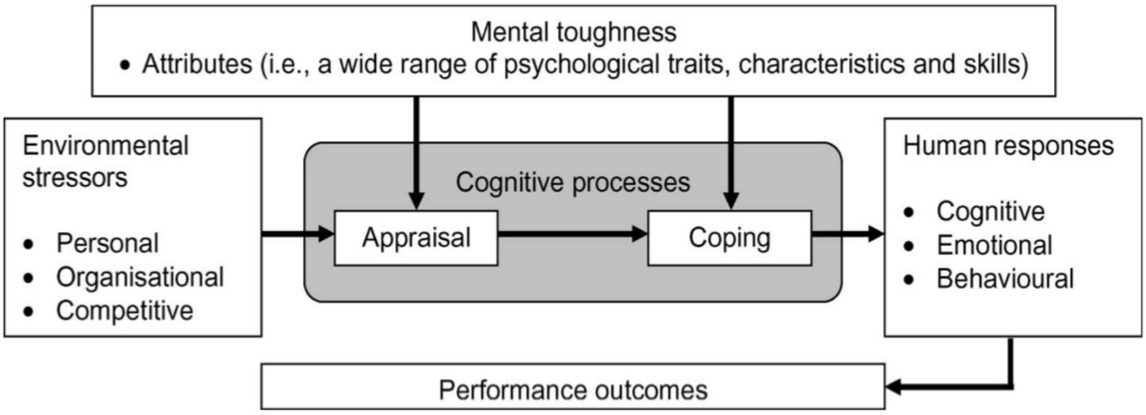
In summary, there are numerous, and varied, definitions of mental toughness, with many psychological attributes being linked or correlated to success, including the ability to handle pressure and adversity, resolve to overcome failures, or possession of superior mental skills for use during performance. Early definitions of mental toughness were based on the experience and opinion of sport professionals, including athletes and coaches and relied on analysis of largely self-report questionnaires rather than scientific investigation (Connaughton et al., 2013; Gucciardi, 2017).

Despite criticism, the concept, model and theories of mental toughness continue to evolve (Gucciardi, 2017). The MTQ48, emerged from a significant body of research, is built on the construct of hardiness, and is used to explain stress reactions, in health psychology literature. Possibly due to its ease of use and scoring it remains the most widely used tool for the measurement of mental toughness in sport (Gucciardi et al., 2012; Vaughan et al., 2017). Furthermore, recent research sampled elite, amateur athletes and non-athletes, and identified high levels of internal consistency in the MTQ48, with the six-factor model - including life and emotional control, along with confidence in interpersonal skills and abilities - resulting in an acceptable, and better fit than the four-factor model (Vaughan et al., 2017). Therefore, for the purposes of the current programme of research, and in the absence of other measures, the MTQ48 will be used to quantify mental toughness in non-elite, ultra-runners, and non-ultra-runners, to contribute to the body of knowledge regarding both mental toughness and endurance in sport.

Measurement of mental toughness, along with the quantification of physiological parameters associated with performance, will provide insight into the relationship with environmental stressors in the ultra-marathoner. According to Fletcher (2005) the attributes of mental toughness, influence an individual's appraisal and coping of a particular situation and subsequently moderate the relationship between stressors and cognitive, emotional and behavioural responses (see Figure 2.2).

Figure 2.2

Facet Model of Mental Toughness and Human Performance (Taken from Fletcher, 2005)



Other factors may also affect the cognitive processes involved. Whilst Mahoney, Ntoumanis, Mallett and Gucciardi (2014) confirmed the importance of mental toughness they also suggested links to variables within motivation and encouraged further research to support optimal human functioning as opposed to the mental toughness construct. Responding to this recommendation, motivation is discussed next.

2.2.2. Motivation

This section provides an overview of motivational theories of behaviour prior to discussing measures, and their application to endurance athletes.

2.2.2.1. Definition of Motivation and Theoretical Background

Motivation has been defined as what maintains, sustains, directs and channels human behaviour over an extended period of time (Ryan & Deci, 2017; Tsigilis, 2005). Motivation impacts an individual's ability to focus, and willingness to achieve excellence through mental and physical effort and is likely to be a necessary precursor to the adoption, and the ongoing continuance, of training to participate in ultra-marathon events (Hanson, Madaras, Dicke, & Buckworth, 2015; Zach et al., 2017). The ability of the ultra-marathoner to focus on training and competition is often restricted in terms of both time and resources, and relies on a state of heightened motivation, and enthusiasm, to balance dedication towards sport against family commitments, illness, injury, and work pressures (Krouse et al., 2011). Though researchers have identified both training intensity, and running volume, as predictors of race time, it is unclear the role, or impact, of motivation on participation, or success, in ultra-marathon events (Hoffman & Krishnan, 2013; Knechtle, Rosemann, Knechtle & Lepers, 2010; Knechtle, Wirth, Knechtle, Rust & Rosemann, 2012).

2.2.2.2. Theories of Motivation

Many psychological theories have been proposed to explain exercise adherence (Biddle, Mutrie & Gorely, 2015). Some of these include the Theory of Planned Behaviour (TPB) (Ajzen, 1985, 1987, 2002), the Theory of Competence Motivation (Carter, 1985), the Social Cognitive

Theory (Bandura, 1977), and Self-determination Theory (SDT) (Deci & Ryan, 1985: for a review of theories see Biddle, Mutrie, & Gorely, 2015). SDT was used in this research due to its organismic perspective and its assumption that humans have evolved to be both curious and intrinsically motivated to be physically active (Ryan & Deci, 2017).

Theory of Planned Behaviour

The Theory of Planned Behaviour (TPB) provides a useful account of how attitudes and beliefs impact conscious, behavioural change (Ajzen, 1985, 1987; 2002; Palmer, Burwitz, Dyer, & Spray, 2005). TPB is a widely-tested, social, cognitive model that has been applied successfully in the prediction of health-related behaviour, including the adoption of healthy lifestyles, physical activity/exercise and diet (Gucciardi & Jackson, 2013). According to TPB, beliefs form a favourable, or unfavourable, impact on the attitude towards that behaviour, which along with both perceived social pressure, and behavioural control, form the behavioural intention to determine and control how that individual acts, and the amount of effort invested (Ajzen, 1985, 1987; 2002; Palmer et al., 2005). Intention is influenced by three factors: the positive or negative evaluation of participating in a human behaviour; the social pressure regarding performing, or not performing that behaviour; and the perception of how difficult the behaviour is to perform (Ajzen, 2002). Consequently, the intention to participate in a chosen activity is elevated when attitudes related to that behaviour are positive, when others appear to support the behaviour, and an increased perceived ability to carry out that behaviour (Gucciardi & Jackson, 2013).

TPB has been utilised successfully to predict adherence to training in female netball players and it has subsequently identified links between positive attitudes and the determination of behaviour of young people in organised sport; less success has been observed in predicting training variation from a range of sports (Anderson & Lavallee, 2008; Gucciardi & Jackson, 2013; Palmer et al., 2005). Palmer et al. (2005) recognised that a possible explanation for the limited ability of intentions to predict training behaviour, resulted from motivational changes over time being as an outcome of new information. However, despite success in linking behavioural intentions with sport continuation in a number of individual and group sport (Gucciardi & Jackson, 2013), no research into TPB has been completed with ultra-marathoners.

Theory of Competence Motivation

The Theory of Competence Motivation (TCM), is based on the premise that perceiving either a level of mastery, or competence, in a behaviour will increase the likelihood that it will be repeated (Harter, 1978). Positive feedback may lead to an improvement in self-perception that results in repeated behaviour, whilst negative feedback may result in a fear of failure, and a reduced likelihood of repeating the activity. Harter (1978) proposed that development can be improved through removing, or reducing, the fear of a lack of success, and through support and positive feedback, leading to improvements in perceived success and competence, and a greater likelihood of repeated behaviour. Early research identified support for TCM and recognised relationships between perceived competence and the motivation to participate in sport (Klint & Weiss, 1987). Subsequent research by Tsigilis (2005), indicated that perceived competence significantly predicted success in endurance, and that it logically precedes intrinsic motivation. However, the research has been limited to a shuttle test as a measure maximal aerobic fitness and may not be representative of performance under race conditions or in line with the direct measurement of $\dot{V}O_{2max}$. Rheinberg and Engeser (2010) proposed that the components of motivational competence include the ability to confer situations with motive congruent incentives, and that those people higher in motivational competence are less likely to take part in activities that are incongruent with their motives.

Social Cognitive Theory

The Social Cognitive Theory (SCT) is based on the premise that learning, and behavioural adaptations, occur as an outcome of observing others within the context of social interactions and experiences (Bandura, 1986). The theory predicts that witnessing a person performing an action provides the observer with a useful cognitive representation and facilitates performance improvement, and furthermore, that learning can occur without participating in the action but as a result of forming models using verbal, or visual imagery (Bandura, 1986). A systematic review by Young et al. (2014) proposed that SCT is a useful model to explain physical activity behaviour but currently falls short of examining competitive, or endurance sport. Indeed, much of the research into SCT is within the field of social and health psychology and in particular behavioural change through media campaigns. To date, no research examining SCT has identified the impact of knowledge acquisition, and behavioural modification, in ultra-marathoners through the observation of others on endurance performance (Rosário et al., 2017). This may in part be due to the suitability of SCT to explain performance success through motivation. A likely more suitable theory to endurance motivation is the Self-determination Theory (Ryan & Deci, 2017).

Self-determination Theory (SDT)

The Self-determination Theory (SDT) is an organismic theory of human motivation based on people's inherent tendency towards growth, and the degree to which their behaviour is self-motivated (Deci & Ryan, 1985). Ryan and Deci (2017) propose that humans have an evolved the ability, and propensity, to realise their human capacities and attain healthy psychological, social and behavioural functioning. SDT proposes that humans are adapted to be innately curious, socially, and physically active, and that motivation results from the constant interaction between human nature and socially contextual factors. As a result, activity is most likely when an individual feels they are intrinsically motivated and have volition over their behaviour (Deci & Ryan, 1985; Ryan & Deci, 2017). Intrinsically motivated people behave as they do, because they find the activity they are taking part in inherently interesting and appealing. Extrinsically motivated behaviour is usually driven by participating in an activity that has an external consequence, for example, the acquisition of monetary rewards, or the avoidance of chastisement (Deci & Ryan, 2008). The introduction of extrinsic factors, even when individuals are free to follow their own desires, can lead to a movement in the locus, or origin, of causality, and a corresponding reduction in intrinsic motivation (Deci & Ryan, 2000). The internal locus of causality indicates autonomous, intrinsic motivation, and the perception that the actor is the origin of their behaviour, rather than simply being subject to external forces (Ryan & Connell, 1989).

Deci and Ryan (1985) propose innate and universal psychological needs that act to motivate behaviour and provide essential nourishment to ensure the psychological health and well-being of the individual. Central to SDT is the idea that optimal performance and maximal perception of well-being tend to occur when the following three basic psychological needs are met:

relatedness, competence and autonomy (Ryan & Deci, 2017). Relatedness is concerned with a sense of belonging, feeling significant to others, and refers to the need to feel connected to family, peers and society. Competence is our basic need to feel capable of operating effectively within salient life contexts and is identified with the desire to be open to new life experiences and to learn from them (Deci & Ryan, 2008; Ryan & Deci, 2017). Autonomy stems from the desire to feel free to make decisions and choices within situations, congruent with one's authentic interests, and is indicative of improvements in performance, persistence and adherence (Ryan & Deci, 2017). Autonomous motivation contrasts with controlled motivation which is focussed on delivering specific outcomes, usually arising from forces believed external to the self, and is postulated to be essential to intrinsic motivation, and may be subverted, by external influences, or pressures, including meeting deadlines, appraisals, or monetary rewards (Deci & Ryan, 2000). Contexts that enable satisfaction of the basic psychological needs are proposed to enhance autonomous motivation, which is made up of intrinsic motivation, and extrinsic motivation that has been sufficiently internalised (Deci & Ryan, 2008). Life with a focus on intrinsic goals is more likely to increase psychological needs satisfaction and positive effects on well-being, whilst a focus on extrinsic goals may result in mental health issues and a lack of general wellness.

Research conducted within SDT has identified that individuals with high scores in the autonomy orientation have more positive relationships, health-related behaviour and self-actualisation (Deci & Ryan, 2000). In contrast, a controlled orientation is more closely related to feelings of self-consciousness, being under pressure, and adopting a more outward focus. The SDT has been applied to multiple fields, including education, sport and business and despite primarily being a psychological model, the theory is concerned with both evolutionary and biological, as well as cultural, including familial and denial of human rights, and economic factors, such as capitalism (Ryan & Deci, 2017). As a result, five mini-theories within SDT have been proposed that correspond to multiple aspects of psychological integration and motivation, rather than the traditional fields, and elements, of psychology. Early research by Deci and Ryan (1980) resulted in the formulation of the Cognitive Evaluation Theory, used to describe the processes involved in the influence of social environments on intrinsic motivation, and its impact on performance and well-being. Subsequent mini-theories include the Organismic Integration Theory describing the development of extrinsic motivation as a result of integration, and the move towards autonomy (Ryan, Connell & Deci, 1985). The third mini-theory, the causality orientations theory (COT), explores the personality and developmental aspects of the SDT, where individual differences constitute the developmental outcome as the individual interacts with the social environment over time (Deci & Ryan, 1985a; Ryan & Deci, 2017). The COT aims to measure lasting aspects of the character and predict meaningful outcomes rather than 'needs' (Deci & Ryan, 1985a). SDT COT proposes three general causality orientations, autonomy, impersonal and controlled, and intends to describe orientations towards both one's own motivations and that of the environment (Ryan & Deci, 2017). The autonomy orientation suggests acting with autonomy, in spite of the environment controlling aspects of behaviour, through an orientation towards values and interests within an interpersonal context. The control orientation refers to an inclination toward behaviour that is regulated and controlled by social situations and contingent on reward, and the potential to interpret situations as being controlling, despite autonomous opportunities. The impersonal orientation indicates that tendencies toward elements of the interpersonal context that may be identified with a lack of control over outcomes, and promote amotivation (Ryan & Deci, 2017). A fourth mini-theory, the Basic Psychological Needs Theory, has been developed to better understand how needs support, and affect, psychological health and well-being, and a fifth, the Goal Contents theory, relates to peoples' goals, intrinsic and extrinsic motivation, and relations to basic needs satisfaction (Ryan & Deci, 2017).

Collectively the five mini theories provide explanations of behaviour that may include both elements of intrinsic and extrinsic motivation. COT, in particular, consists of three heavily researched individual differences, the impersonal orientation, autonomy orientation, and the control orientation, and will form part of this programme of research to provide useful insight into the preparation for, and participation in, ultra-marathon events.

2.2.2.3. Measurement of Motivation

According to Deci and Ryan (2017), one of the central purposes for identifying individual differences in causality orientations is to better understand individuals acting autonomously in controlling or in intrinsically motivating situations or environments, where autonomy is undermined. People may identify meaning, and act accordingly, without submitting to the objective characteristics of the context.

Deci and Ryan (1985) constructed and validated the General Causality Orientation Scale (GCOS) to measure enduring motivational orientations. The scales comprise of 12 vignettes and 36 items that describe typical, social and achievement-oriented situations, including job application and relationships with friends, with responses indicating either an autonomous, controlled, or impersonal type of motivation (Deci & Ryan, 1985). Each item following the vignette is attributable to one of the three orientations, either autonomy, impersonal or control (Deci & Ryan, 1985). A number of studies have confirmed the effectiveness of the GCOS instrument in quantifying causality orientations (Cooper, Lavaysse & Gard, 2015; Koestner, Bernieri, & Zuckerman, 1992).

According to Ryan and Deci (2017) persistent variation in contextual support, contrasted with deprivations, can result in significant individual differences, in individuals' orientation to the environment. General causality orientations reflect people's propensities across time and contexts, and orientations to one's own environment. To capture these individual differences, in Studies 2 and 3, the SDT General Causality Orientation Scale (GCOS) has been used to measure each of the three orientations, autonomy, impersonal and control, and identify intrinsic, and extrinsic motivational individual differences between the ultra-marathoner and the non-ultra-marathoner. Analysis of the measurements will provide a degree of insight into the motivation of amateur athletes to train for and participate in ultra-endurance events.

2.2.2.4. Critical Appraisal

To date, SDT has not been used to distinguish between the motivation of the ultra-marathoner, and the non-ultra-marathoner whilst controlling for physiological markers of aerobic fitness. Therefore, research into motivation and the ultra-marathoner, using SDT, is warranted, due to its success in explaining variance in health-related exercise behaviour, its relative simplicity, and the suggestion that satisfaction of basic needs, including autonomy, relatedness and competence, are likely to predict positive sporting outcomes (Deci & Ryan, 2017; Hagger & Chatzisarantis, 2008). Furthermore, from Ryan and Deci's (2017) proposal that humans have evolved to realise our capacities and be innately curious, it may be speculated that ultra-marathoners by their nature, are motivated to participate in races for personal achievement, and push the limits of experience and capabilities (Simpson et al., 2014).

A greater understanding of ultra-marathoners' motivation to run, and the links between motivation and endurance success, may enable the sports professional to better support the ultra-marathoner in both training and race situations and potentially reduce the likelihood of burnout, where perceived demand exceeds personal resources (Chang et al., 2017; Lonsdale, Hodge & Rose, 2009).

2.2.3. Personality

A considerable amount of personality in sport studies has been published (Kaiseler, Levy, Nicholls, & Madigan, 2017), but only a limited number have explored the personalities of athletes who participate in events that are defined by arduous running conditions, over many hours, and possibly days (Freund et al., 2013; Roebuck et al. 2018). This section explores some of the background and key findings from research into personality that may assist forming an understanding of amateur athletes who participate and perform well in ultra-endurance events.

2.2.3.1. Theoretical Background of Personality

Personality is defined as those psychological qualities that contribute to an individual's lasting way of thinking, behaving and feeling (Allen, Greenlees, & Jones, 2011). It is widely accepted that personality determines the behaviour of competitive athletes and as a result has received considerable attention within the domain of sport (Kaiseler et al., 2017). Trait-based assessments of natural language have been used to describe the basic personality dimensions on which people are said to differ, and consensus has been reached regarding a five-factor model of personality dimensions (McCrae & John, 1992; Allen et al., 2013). This agreement led to the creation of a hierarchical, five-factor model of personality, including neuroticism, extraversion, agreeableness, conscientiousness, and openness to experience, that maintains cross-situational consistency, and has been shown to capture much of the personality variance (Allen et al., 2013; Kaiseler, Polman & Nicholls, 2012; McCrae & John, 1992). Each of the traits can be further subdivided into a number of other specific traits, or facets, for example, neuroticism, which encapsulates depression, anxiety, and self-consciousness (Allen et al., 2013). According to the definitions provided by Kaiseler et al. (2012), *neuroticism* is contrasted with emotional consistency, and even-temperedness, and includes the generation of irrational ideas; *extraversion*, suggests an energetic response to both the social and material world, along with an inclination to experience positive emotions, and self-assurance; *agreeableness*, suggests an orientation towards the social and the communal, along with being helpful and trusting; *conscientiousness*, describes impulse control, benefiting both task and goal-directed behaviours, and implies self-discipline; *openness to experience*, suggests the extent of an individual's complexity regarding both experiential and mental life, including creativity and inventiveness, flexible thinking and unconventionality. The major theoretical descriptions of personality in sport are presented below.

2.2.3.2. The Big 5 Factor Model of Personality in Sport

Five personality dimensions are frequently used as a framework for investigating personality, with researchers indicating that higher-order personality dimensions influence an athlete's ability to cope with pressure and both short-term behaviours, and long-term success in sport (Allen et al., 2011; Allen et al., 2013; Kaiseler et al., 2017). Research to understand individual differences in sport has either focussed on the comparison of measurements taken between diverse populations, including athletes and non-athletes, or, between discrete groups of athletes, including athletes in diverse sports, or elite versus recreational athletes (Allen et al., 2011). Analysis of findings has led researchers to suggest that athletes tend to have increased scores in extraversion, and lower scores in neuroticism, than non-athletes, and that personality may determine long term success in sport, however concerns have been raised regarding research design including diversity of populations and underlying conceptualisation of personality (Allen et al., 2011; Allen et al., 2013). Players of team sports have been identified with higher levels of extraversion, but lower levels of conscientiousness. Research has also demonstrated that scores from personality tests may differentiate between athletes and non-athletes and between athletes in different sports (Allen et al., 2013). Research by Nia and Besherat (2010), identified that athletes were more conscientious than team sport athletes, but that the latter were more agreeable.

In contrast to research in education and organisational settings, studies to identify whether personality can predict performance success in sport, and to identify personality profiles that distinguish athletes from non-athletes, have failed to report consistent patterns making any conclusions equivocal (Allen et al., 2011; Kaiseler et al., 2017). Coping, identified as the ability to manage specific demands, through the ongoing monitoring, cognitive and behavioural modification, is important to sporting performance, but research has had limited success linking it to personality dimensions (Allen et al., 2011). Subsequent investigations into coping strategies in athletes, by Allen et al. (2011) and Kaiseler et al. (2012), identified that extraverted athletes were more problem-focussed, especially those higher in openness, whilst athletes higher in conscientiousness were more likely to adopt emotion-focused coping strategies. Their research identified that those athletes who are lower in openness to new experience were more likely to cope through the avoidance of problems and stressors, and that higher-level athletes were likely to be more conscientious, compassionate and emotionally stable (Allen et al., 2011). Increased neuroticism appears to have a negative effect on coping strategies, possibly as a result of exaggerating the size of the threat posed by a situation or event (Kaiseler et al., 2012). The advantage of increased extraversion may be as a result of increased effort, and seeking out, and engaging with support, whilst in contrast, agreeableness is associated with lower levels of active coping (Kaiseler et al., 2012). Overall, research implies that the Big 5 personality dimensions influence both appraisal and coping: whilst neuroticism was associated with the selection of less successful coping strategies, conscientiousness, openness, extraversion and agreeableness were linked to more adaptive, effective coping strategies (Kaiseler et al., 2012). Furthermore, the increased extraversion, conscientiousness, and reduced neuroticism scores are likely to benefit athletes, and increase their participation in sport, through the preparation and early involvement in sport (Nia & Besherat, 2010). Horsburgh et al. (2009) performed research into the factors that contribute to individual differences in behavioural traits and identified a 50% heritability of each of the 5 personality traits, openness, extraversion, neuroticism, agreeableness and conscientiousness, along with numerous correlations with the dimensions of mental toughness.

2.2.3.3. Applying the Big 5 Factor Model of Personality to Endurance Sports

Though research into endurance sports, using the Big 5 personality dimensions, is limited and findings inconsistent, analysis of personality using multiple instruments, has suggested that ultra-marathoners are identifiable by their personality traits (Roebuck et al., 2018). A review of literature performed by Roebuck et al. (2018) identified nine studies that explored the personality traits of ultra-marathoners. Only four of the studies had been published in the last twenty years, and none used the Big 5 personality questionnaire: Krouse et al, (2011) focussed on motivation and goal orientation; Hashimoto, Hagura, Kuriyama, and Nishiyamai (2006) used the Myers-Briggs Type Indicator (MBTI) to identify that ultra-marathoners are more introverted; and Martinez and Scott (2016) identified ultra-marathoners as being more neurotic, using a ten item personality measure. The fourth study, Hughes et al. (2003), investigated a group of ultra-marathoners participating in a single event, to identify their personality profiles, in contrast to a normative population. Consistent with previous research, race participants scored significantly higher in extraversion, along with openness. More recently, a study including participants in the TransEurope footrace, a 4487k, multi-day event, identified ultra-marathoners as having a low perception of pain, more self-centred and were less cooperative (Freund et al., 2013). In contrast, a qualitative study, to explore competition and training experiences, identified ultra-marathoners as having a willingness to endure pain, whist highlighting the importance, and reliance on, the ultra-running community to provide practical advice, camaraderie and encouragement (Simpson et al., 2014).

2.2.3.4. Critical Appraisal

Though further study is warranted, research confirms that identification of personality traits can predict both long term success and short-term behaviour and can be used to discriminate between athletes and non-athletes (Allen et al., 2013). However, although personality may be an influencing contextual factor, little is known regarding its effect on cognitive appraisals, coping effectiveness during performance in sport, and/or the ability to handle stress without impact to performance (Allen et al., 2013; Kaiseler et al., 2012). Therefore, further research is required to extend knowledge of how psychological factors, including personality, contribute to successful performance in ultra-marathoners.

2.3. Physiological Approach to Endurance

There has been extensive research into ascertaining the physiological factors that affect human endurance performance, including maximal oxygen uptake, lactate threshold and running economy (Barr, Clark, Corbett, & Draper, 2018; Hawley et al., 2014). To date, a large number of studies have examined the mechanisms that affect and influence performance in aerobic exercise, however comprehensive studies using ultra-marathoners are limited. Section 2.3 assesses research into key physiological factors that impact aerobic fitness and subsequently human capacity for endurance.

Aerobic exercise leads to an increased metabolic response that challenges the homeostasis of the whole body, and can result in disruption to tissues, cells, and organs, alongside changing an individual's oxygen uptake and lactate threshold (Caputo & Denadai, 2004; Hawley et al., 2014). It is widely accepted that endurance training is affected by specificity of both exercise mode and activated muscle mass and leads to a number of physiological changes and health benefits, including aerobic and cardiovascular fitness. However, research has postulated that aerobic training may have an upper limit to maximise health benefits, but confirms that physically active men and women, compared with the inactive, have a 30% lower risk of death (Schnohr, O'Keefe, Marott, Lange, & Jensen, 2015).

2.3.1. Aerobic Capacity – $\dot{V}O_{2max}$

This section provides an overview of some of the key factors that affect maximal oxygen uptake, its measurement, and its potential impact on performance in ultra-endurance athletes.

2.3.1.1.Definition and Theoretical Background

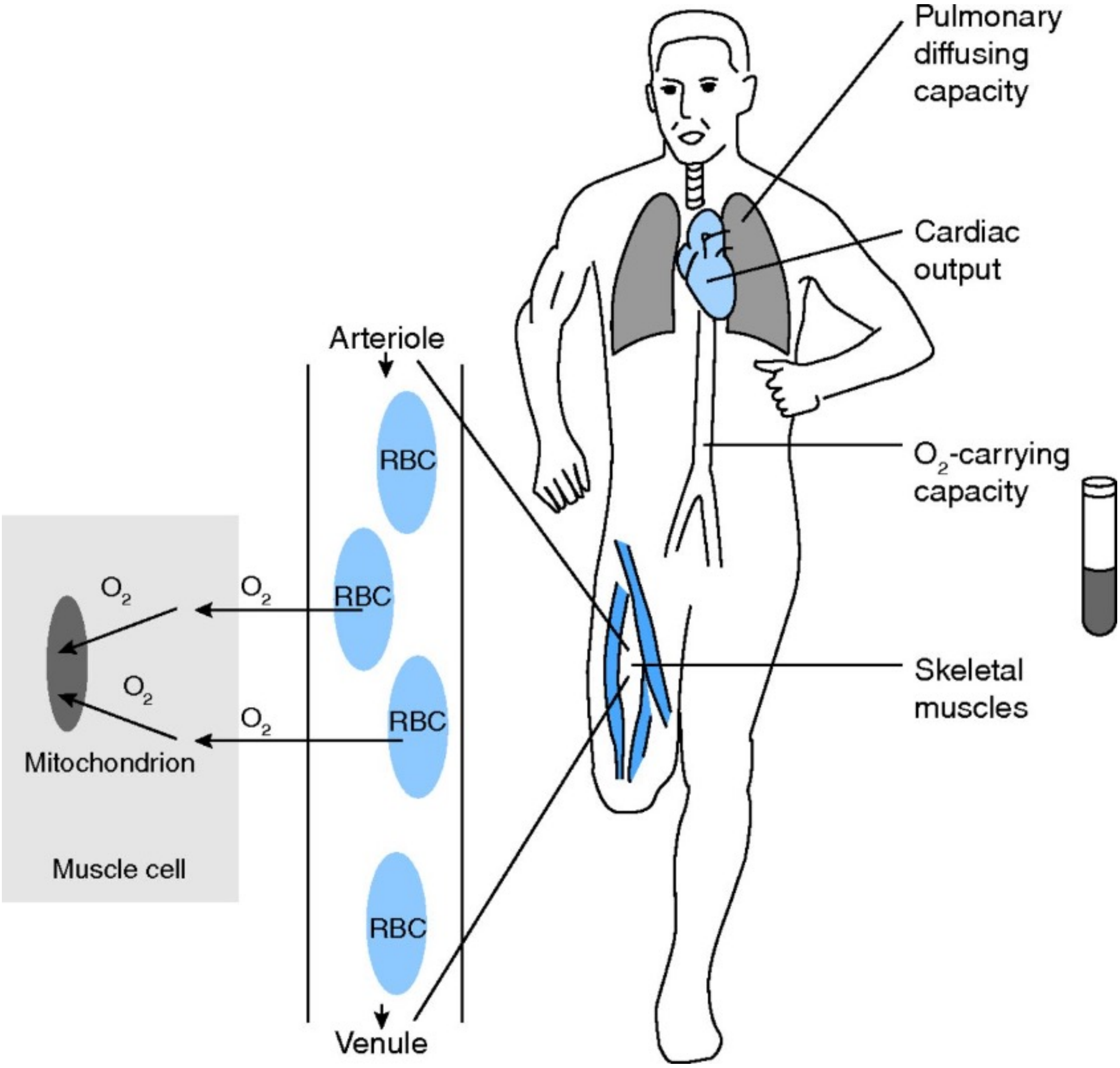
Maximum oxygen uptake ($\dot{V}O_{2max}$) is a measure, during maximal exercise, of the highest rate that oxygen is consumed by the mitochondria during oxidative phosphorylation; the metabolic pathway by which enzymes are used by cells to oxidise nutrients and subsequently release energy in the form of adenonsine triphosphate (ATP) (Bassett & Howley, 2000; Schnohr et al., 2015). $\dot{V}O_{2max}$ is widely accepted as an indicative measure of aerobic fitness and is used to both assess aerobic fitness, and as a guide for training sessions (Mazzoleni et al., 2017; Midgley, Mcnaughton & Wilkinson, 2006).

There has been a long-term interest in deciphering the factors and mechanisms that limit $\dot{V}O_{2max}$, alongside determining its role in endurance performance. The classical view of maximal oxygen uptake originally put forward by A.V Hill et al. (1923, 1924), proposes that $\dot{V}O_{2max}$ is limited by the cardiorespiratory systems' ability to deliver O_2 to working skeletal muscles. According to Hill's model, there is a physiological upper limit to maximal oxygen uptake, beyond which it does not continue to rise (Faude, Kindermann & Meyer, 2009). Consequently, a runner's performance may be restricted as a result of either a low oxygen uptake, a reduced upper limit of maximal oxygen uptake, or increased oxygen requirements (Bassett & Howley, 2000). The Central Governor Model (Noakes, 2004, 2007), and the Psychobiological model (Marcora, 2008; Marcora et al., 2009; Marcora & Staiano, 2010), in Section 2.4, refute this viewpoint, and propose that the brain *per se* plays a major contributing factor.

Previous work has outlined the key components and systems that affect maximal oxygen uptake, including, to varying degrees (see Figure 2.3): an increased maximal stroke volume leading to an increased blood flow; the delivery of O_2 by the pulmonary and cardiovascular system to the contracting skeletal muscles; the capacity of the blood to carry oxygen in the haemoglobin; the density of capillaries in muscle fibre; the quantity of the motor units recruited by the central nervous system; and the capacity of the muscles engaged to consume the oxygen (Bassett & Howley, 2000; Hawley et al., 2014).

Figure 2.3

Factors that control oxygen consumption during exercise (taken from Cooper, 2008)



2.3.1.2. Measurement of $\dot{V}O_{2max}$

$\dot{V}O_{2max}$ can be determined through a number of aerobic tests that activate the large muscle groups and, as a result of appropriate exercise intensity and duration, maximise the aerobic energy transfer (Mier, Alexander, & Mageean, 2012; Nevill & Cooke, 2017). Experimental testing to measure maximal aerobic uptake, usually rely on a continuous, supramaximal exercise challenge, often on a treadmill or a stationary cycle, involving increasing increments of difficultly, or load, until the participant reaches volitional exhaustion (Evans, Ferrar, Smith, Parfitt, & Eston, 2015; Mier et al., 2012). $\dot{V}O_{2max}$ scores usually differ depending on the mode of exercise, and the muscle fibres and groups recruited, with the highest $\dot{V}O_2$ scores habitually achieved when performed on a treadmill. The test protocol must be of sufficient duration to reach a $\dot{V}O_2$ plateau, whilst increasing the load sufficiently quickly to ensure other mechanisms of fatigue do not cause the participant to stop the test prior to reaching $\dot{V}O_{2max}$ (Mier et al., 2012). To achieve $\dot{V}O_{2max}$ the participant must (a) reach a point where their $\dot{V}O_2$ becomes linear, despite an increasing work rate, (b) achieve a heart rate within 10 beats of their maximum, (c) reach a respiratory exchange ratio greater than 1.15, and (d) a rating of perceived exertion above 17 on the Borg scale (Haff & Dumke 2012; Mier et al., 2012). Additional secondary criteria, including blood lactate concentration, have been established, but concerns have been raised regarding their reliability (Mier et al., 2012). Where a test is concluded without any of the preceding conditions met, the term *peak oxygen consumption* ($\dot{V}O_{2peak}$) is adopted and could be due to motivation or muscular factors (Mier et al., 2012).

Further detail of the protocol used in this programme of research to measure $\dot{V}O_{2max/peak}$ is given in Section 3.

2.3.1.3. Critical Appraisal of $\dot{V}O_{2max}$

A large body of related research in sports science, has confirmed the value of quantifying maximal aerobic uptake, with a significant variation in $\dot{V}O_{2max}$ existing between the aerobically trained and untrained (Schnohr et al., 2015). However, concerns have been raised regarding the efficacy of existing maximal oxygen uptake test protocols, analysis of the data, and the lack of consistency and accuracy of the equations used in the calculations (Evans et al., 2015). Tsigilis (2005) suggests that the psychology of the participant is likely to impact the measure of maximal oxygen uptake. Data from shuttle tests, a field-based assessment of maximal oxygen uptake, have identified that perceived competence, an important antecedent of intrinsic motivation, was a significant predictor of $\dot{V}O_{2max}$. Reaching a plateau in oxygen consumption requires a high level of anaerobic energy output and dealing with the accompanying discomfort may prove difficult for an untrained individual, relying heavily on motivational factors (Evans et al., 2015; Mier et al., 2012).

Despite a plethora of training protocols placing a great deal of reliance on the outcome of $\dot{V}O_{2max}$ tests, doubts have been raised regarding the measures ability to predict success in endurance events (Midgley et al., 2006). According to research by Knechtle et al. (2010, 2015) maximal oxygen uptake was not the principal variable to predict the successful outcome of an ultra-marathon, but instead reported, age, anthropometric characteristics, such as body mass index, limb circumference, and training characteristics including running speed, training volume and prior race experience.

For a further consideration of factors that may affect the voluntary termination of an aerobic session, see Section 2.4 for a discussion of the Central Governor Model (Noakes, 2004, 2007) and the Psychobiological model (Marcora et al., 2009, 2010).

2.3.1.4. Application and Research into Endurance using $\dot{V}O_{2max}$

Over the last decade, a number of investigations have explored, with conflicting results, maximal oxygen uptake in relation to endurance athletes, in an attempt to understand whether $\dot{V}O_{2max}$ predicts completion or performance within ultra-marathon events. Analysis of measurements taken over the course of a 24-hour treadmill run identified that both the $\dot{V}O_{2max}$, and the energetic cost of running, increased until a plateau was reached after 8 hours of exercising, and implied a potential trade-off between running speed and cost of running over the course of ultra-marathons (Gimenez et al., 2013). A study of mountain runners suggested that race times were not related to cardiorespiratory fitness measures, but instead were consistent with individual pacing strategies, variations in recovery between stages, and possible factors not measured, including genetics, nutrition training and psychology (Gatterer et al., 2013).

In a further study, also quantifying relationships between physiological measures and ultra-marathon performance, it was determined that a high $\dot{V}O_{2max}$ was associated with faster running times over the course of the race, but did not predict the running distance achieved, however it was proposed that other factors including pacing, nutrition and motivation may restrict the ability to predict race performance (Baumann, Brandenberger, Ferrer, & Otis, 2014). In a recent study, Tan, Tan, and Bosch (2016) quantified the physiological, anthropometric and training characteristics of competitors within a 161km, and a 101km race. No differences were observed between $\dot{V}O_{2max}$ in finishers when compared with non-finishers, but it was observed that the mean distance of the longest training runs in the former was significantly higher.

For completeness, and practicality of testing, the present research will use $\dot{V}O_{2max}$ as a measure of aerobic fitness, to enable comparison between ultra-marathoners and non-ultra-marathoners. The inclusion of other factors, such as motivation, and race time, will enable a comparison with other measures that may have an effect on, or be affected by, oxygen consumption limits.

2.3.2. Lactate Inflection Point

This section provides an overview of the lactate threshold (LT) and its use as a measure of endurance performance.

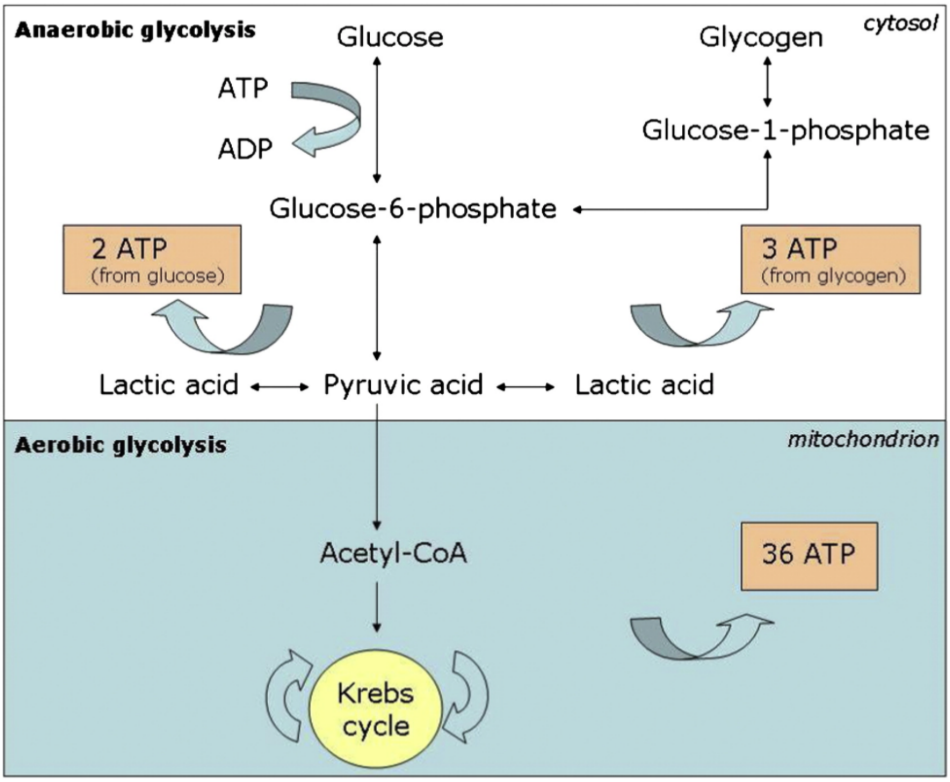
2.3.2.1.Definition and Theoretical Background

Challenges to the classical model of maximal aerobic uptake, and research findings that indicate $\dot{V}O_{2max}$ may be inadequate to measure endurance performance, have led to attempts to identify sub-maximal parameters to measure cardio-respiratory fitness (Faude et al., 2009; Lantis, Farrell, Cantrell & Larson, 2017). As a result, lactate threshold (LT), also known as the lactate inflection point, has become an important indicator of endurance performance, and research suggests more indicative of endurance performance than $\dot{V}O_{2max}$ in homogeneous groups of athletes (Faude et al., 2009). According to research, the percentage of $\dot{V}O_{2max}$ that can be maintained during an endurance event is dependent on the amount of lactate accumulation (Rønnestad & Mujika, 2014). Considerable research data, with a focus on runners, has provided evidence that a lower blood lactate concentration, at a given workload, is indicative of aerobic endurance performance, and is frequently used to indicate the status of aerobic training, and to prescribe training intensities (Faude et al., 2009). LT is a measure of the level of power output, $\dot{V}O_2$ or energy expenditure, where tissue hypoxia triggers an imbalance between the formation, and the clearance, of lactate, leading to an increase in its concentration in blood. As a result, lactate during low intensity exercise rarely exceed sedentary levels, whilst excess lactate provides evidence of anaerobic metabolism (Brooks, Fahey, & White, 2005).

Originally it was understood that lactate was a waste product resulting from glycolysis; the process that converts glycogen into pyruvate, prior to being converted into Acetyl CoA and subsequently entering the Krebs cycle to release energy (Brooks et al., 2005; Faude et al., 2009). However, it is currently known that the process of lactate kinetics is ongoing, whether the body is resting or active, and is closely linked to metabolic rate rather than oxygen availability (Brooks et al., 2005). During intense exercise, lactate accumulates as a result of lactic acid production being greater than removal (Brooks et al., 2005). As exercise intensity increases, blood lactate concentration become higher, due to a number of factors, including: the extra demand for ATP not being met aerobically by mitochondria; and an increased reliance on fast-twitch fibres, which have less mitochondria and produce more lactate (Brooks, 1986; Brooks et al., 2005; Robergs, Ghiasvand, & Parker, 2009).

Figure 2.4

Physiological Map (taken from Melzer, 2011)



Previously published work indicates that as aerobic exercise increases (see Figure 2.4), blood lactate exceeds that of normal variation, and that multiple factors are likely to contribute to the measurement of LT, including, depleted glycogen stores, muscle fibre composition, and capillary and mitochondrial size and density (Faude et al., 2009). As measurement of LT is mode, or task specific, due to the activation of differing muscle mass, values will vary depending whether the protocol dictates using a static cycle or a treadmill. LT will be met at a lower % of the $\dot{V}O_{2max}$ in the untrained, and indeed aerobic training has been shown to impact LT, even when there is little, or no, change to $\dot{V}O_{2max}$.

2.3.2.2. Measurement of Lactate Inflection Point

The lactate threshold has become a standard measure for predicting aerobic capacity and endurance performance, however there are other measures, including the maximal lactate steady state (MLSS) and the onset of blood lactate accumulation (OBLA). MLSS is the maximum power output that can be maintained without blood lactate accumulation and it has been proposed as a reliable marker of endurance performance (Czuba et al., 2009; Faude et al., 2009). OBLA is at a higher exercise intensity than the lactate threshold and is an indication of the point at which lactate production exceeds the rate of clearance (Czuba et al., 2009). A close relationship has been observed between LT, MLSS, and OBLA, however LT is widely used, and accepted as an appropriate measure for predicting aerobic endurance (Czuba et al., 2009; Faude et al., 2009;).

2.3.2.3. Application and Research into Lactate Inflection Point

LT is widely used to determine the effects of multiple modes of training in endurance sports, including running and cycling. Research by Rønnestad and Mujika (2013), used measurements of LT, along with other physiological measures, to identify and report on the effects of both strength, and aerobic training on endurance performance. Basset and Howley (2000) identified the speed of running at LT, as the best measure for predicting endurance running performance, whilst Faude et al. (2009) identified the anaerobic-aerobic transition as being integral for assessing endurance performance.

Lactate threshold is a reliable and consistent measure, which can be used to predict endurance capacity, and is utilised as part of this programme of research to compare both between ultra-marathoners and non-ultra-marathoners, and *within* the ultra-marathoner group. Consequently, the inclusion of psychological measures within the present research makes it viable to compare with lactate accumulation measures and offer an insight into endurance performance.

2.3.3. Running Economy

This section provides an overview of running economy (RE), the factors that affect its value, and the potential impact it has on endurance performance.

2.3.3.1. Definition and Theoretical Background

A growing body of literature investigating the multiple factors involved in sporting success in endurance racing has postulated that performance in events is a product of both maximal sustained power output and, the energy cost of maintaining speed (Bassett & Howley, 2000; Rønnestad, & Mujika, 2014; Vernillo, Millet, & Millet, 2017). Research has identified three physiological attributes that contribute to successful performance in distance running: (a) a high cardiac output and oxygen delivery to working muscles, identified as the $\dot{V}O_{2max}$, that results in a large aerobic adenosine triphosphate (ATP) regeneration capacity; (b) the fractional utilization of $\dot{V}O_{2max}$, or the ability to maintain a high percentage of $\dot{V}O_{2max}$ for the longest time possible; and (c) the ability to move economically, known as the running economy (RE) (Barnes & Kilding, 2014; Joyner & Cole, 2008). Whilst $\dot{V}O_{2max}$ and the fractional utilisation of $\dot{V}O_{2max}$, are well researched, RE has received only limited attention (Barnes & Kilding, 2014). Research into ultra-marathoners has defined RE as a measure of energy demanded as a product of the interaction between both biomechanical and physiological factors, expressed as the submaximal oxygen uptake ($\dot{V}O_2$), to run at a given running velocity (Bassett & Howley, 2000). RE explains, in part, the performance differences between athletes of comparable $\dot{V}O_{2max}$, and may provide insight into study findings confirming that the highest $\dot{V}O_{2max}$ does not necessarily identify the athlete most likely to produce the best performances (Bassett & Howley, 2000;

Rønnestad, & Mujika, 2014). However according to a review by Joyner and Cole (2008) there are no longitudinal studies on endurance athletes that confirm the trainability of running economy over several years. Trained, as opposed to untrained, runners can however be recognised through an improved RE: a likely response to a number of adaptations, including oxidative muscle capacity, biomechanical changes and haematological changes, resulting in increased red cell mass (Barnes & Kilding, 2014). However, studies into acute and chronic interventions have reported that uphill, and high intensity running on flat-ground, alongside plyometric and strength training, result in increased running economy (Barnes & Kilding, 2014; Rønnestad, & Mujika, 2014). Exercise training appears to increase endurance performance partly as a result of improvements to neuromuscular activity, increased musculo-tendinous stiffness, and the conversions of some fast-twitch fibres to more fatigue-resistance fibres (Rønnestad, & Mujika, 2014; Barnes & Kilding, 2014). Analysis of research suggest that positive changes to running economy reflect improved oxygen consumption at submaximal exercise intensity levels and are likely to be accompanied by an increased long-term endurance, brought about by delaying fatigue, and enhanced anaerobic capacity and maximal speed (Rønnestad, & Mujika, 2014). However, Joyner and Cole (2008) offer a word of caution against explanations resulting purely from scientific reductionism and impress the importance of the role of motivation and sociological factors. Running economy is therefore likely to be one of many interrelated psychophysiological factors and must not be considered in isolation.

2.3.3.2. Measurement of Running Economy Concept

RE is usually represented as the submaximal oxygen ($\dot{V}O_2$) at a pre-defined running velocity, typically 16km per hour (Barnes & Kilding, 2014).

Further detail regarding the protocol used in the measurement of RE is included in Chapter 3.

2.3.3.3. Application/Research into Endurance

Running economy has been recognised as a key factor in success at races up to marathon distance, but limited research has been undertaken to better understand its role in ultra-marathon running. A review performed by Vernillo et al. (2017) to better understand the role of fatigue on RE concluded that research into the impact of running ultra-marathons remains unclear. Additionally, agreement has not been reached regarding the most economical running technique, or whether improved RE, as a result of training for an ultra-marathon, benefits, or predicts, endurance performance during competition (Moore, 2016). Further interdisciplinary research is warranted in a combination of kinetic, neuromuscular and anatomical factors.

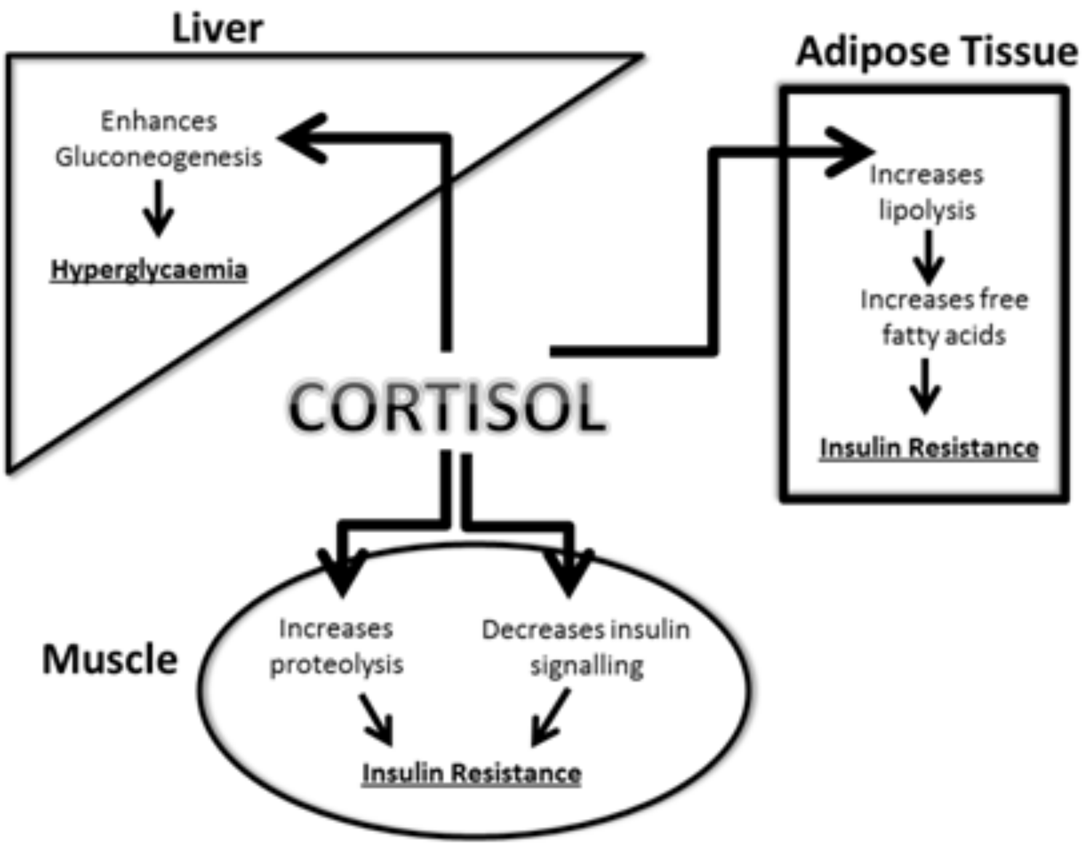
2.3.4. Stress Hormones

2.3.4.1. Theoretical Background of Stress Hormones

Work has focussed on the effects of aerobic exercise, in competitive sports, on the stress hormones, cortisol and testosterone, but largely ignored its relationship to aerobic limits in endurance (Kivlighan, Granger, & Booth, 2005; Lac & Berthon, 2000). Researchers have previously highlighted the positive effect that stress hormones have on an athletes' performance, and conversely the impact that exercise can have on vascular measures of cortisol and testosterone. However, despite being widely investigated, no consistent response to acute, chronic, physical, psychological or immunological stressors, has been identified (Deneen & Jones, 2017; Tanner, Nielsen & Allgrove, 2013).

It is however, widely accepted that high intensity exercise impacts the gluco-corticoids, and catecholamine biochemical pathways. Gluco-corticoids are corticosteroids involved in the metabolism of carbohydrates, proteins and fats, through lipolysis, and have anti-inflammatory benefits, whilst catecholamine biochemical pathways, cause general physiological changes that prepare the body for exercise (Deneen & Jones, 2017). In response to physiological stress, cortisol stimulates gluconeogenesis to initiate glucose maintenance (see Figure 2.5). Both psychological and physiological stressors, can be a factor in the activation of the Hypothalamic-Pituitary-Adrenal axis (HPA), and the subsequent release of the stress hormone, cortisol. This hormone is the primary glucocorticoid present throughout the body, and once released, can directly affect physiological functioning (Deneen & Jones, 2017). Typically, cortisol continues to increase in response to elevated anxiety, exercise intensity, and duration (Hill et al., 2008; Lac & Berthon, 2000).

Figure 2.5
The Effect of Cortisol on Blood Glucose and Insulin Sensitivity in Peripheral Tissues (Al-Sharefi, 2016).



Acute exercise has also been shown to increase testosterone release via a number of mechanisms, including lactate stimulated secretion, and the increase in circulating catecholamines (Tanner et al., 2013). Researchers have observed that testosterone is usually at its highest value near the beginning of exercise, then falls where duration exceeds 3 hours with inter-individual differences impacted by both other factors including diet and circadian rhythms (Hill et al., 2008; Lac & Berthon, 2000).

2.3.4.2. Measurement of Stress Hormones

Whilst cortisol and testosterone concentrations can be quantified in both saliva and blood, salivary samples provide additional, practical benefits by facilitating stress free, non-invasive sampling and subsequent assay analysis, before, during and after competition (Kivlighan et al., 2005; Tanner et al., 2013).

2.3.4.3. Application and Research into Endurance and Stress Hormones

Although extensive research has been carried out on the effect of exercise on stress hormones, results remain inconclusive. A recent study to investigate the effect of long duration racing on the production of cortisol, identified an initial increase, followed by a subsequent reduction over the course of the event (Deneen & Jones, 2017). Continued activation of the stress response can have a negative effect; therefore, a reduction may result from an adaption to prolonged aerobic training. Difficulties have arisen in stress hormone measurement resulting from hormonal variances in response to the time of day, variations in mode of exercise, and the training status of the athlete (Kivlighan et al., 2005; Tanner et al., 2013).

Hill et al. (2008) determined saliva cortisol in athletes at three exercise intensities. Findings demonstrate that only exercise performed at a sufficiently high intensity, 76% of $\dot{V}O_{2max}$, and a long duration, greater than 59 minutes, resulted in a significant increase in cortisol. Whilst, in contrast, biochemistry measured before and after an international rugby match, showed no significant changes in testosterone and cortisol taken both on the morning of the match and 24 hours post event (Crewther et al., 2013).

Further research is warranted to better understand changes in cortisol and testosterone in response to laboratory-based testing, participation in endurance events, and its effect on behaviour including heightened voluntary effort, and choice of workloads (Tanner et al., 2013). This programme of research will also compare changes in stress hormones and other physiological measures, along with psychological factors, to form an improved understanding of the predictors of success in ultra-marathoners.

2.3.5. Genetics

This section provides a brief overview of key research performed in the expanding field of genetics and the impact of the human genome on sporting success.

2.3.5.1. Theoretical Background of Genetics

Approximately 21,000 protein-coding genes within our genome define us as human and are subject to variation as a result of DNA replication, or changes in nucleotide base-pairs (Puthucheary et al., 2011; Willyard, 2018). Darwin's Theory of Natural Selection states that humans with traits most appropriate to their environment, are more likely to reproduce, and subsequently pass on genes (Darwin, 1859; Lippi, Longo, & Maffuli, 2009). Such traits, or phenotypes, result from a complex interaction between our genotype and stimuli from the environment, many of which will impact performance in sport, such as height, muscle strength, and heart and lung capacity (Puthucheary et al., 2011).

Several lines of research over the last decade have led to a growing body of knowledge surrounding the genetic determinants of endurance performance. Findings indicate that an individual's genotype, along with appropriate training, nutrition, and other environmental factors, determine an athlete's phenotype, impacting strength, endurance, potential for injury, and psychological functioning (Carpenter, Garcia & Lum, 2011; Eichhammer, Sand, Stoertebecker, Langguth, 2005; Ghosh & Mahajan, 2016; Lippi et al., 2009). A large body of research has been conducted to explore the genetic influence on both physiological and psychological capacities to perform well in sport, with the HERITAGE family study identifying 29 genes that predicted approximately 50% of the aerobic capacity gains, in response to exercise training (Timmons, 2011).

2.3.5.2. Research into Genetics Impact on Endurance

According to published work, there is a plethora of genes identified that can impact human endurance performance. Two of the most commonly tested with regards sporting performance include the actinin alpha 3 ACTN3 and the angiotensin-converting enzyme ACE gene, the former with regards power and strength in sports, and the latter with regards endurance (Castilha et al., 2018). The polymorphism of the angiotensin-converting enzyme (ACE) gene became one of the first genes identified, and subsequently received a large amount of attention (Bouchard et al., 1995; Puthucheary et al., 2011). Where a polymorphism is a genetic marker representing a molecular characteristic that differs between individuals as identified by two or more alternative forms, or alleles of a gene that occur in the same place in the chromosome (Castilha et al., 2018). Montgomery, Marshall, Hemingway, and Myerson (1998) identified the insertion allele of the gene encoding angiotensin-converting enzyme (ACE) as being associated with endurance performance amongst both mountaineer and elite endurance athletes, whilst there is evidence that the deletion allele is associated with strength, and muscle growth. However, in subsequent research, with military recruits performing a repetitive elbow flexion exercise, success was ascertained as independent of the ACE gene polymorphism, prior to, but not following, training (Puthucheary et al., 2011). Evidence therefore identifies that the presence of the gene alone does not indicate superior performance but rather that it must be coupled with appropriate training for any beneficial effect to be present. Despite Montgomery and colleagues work (1998; 2011) the importance of the ACE gene polymorphism on endurance remains inconclusive and warrants further research. Indeed, Ash et al., (2011) demonstrated that the genomic analysis of world-class Kenyan and Ethiopian athletes, have not reported an increased presence of the ACE gene polymorphism when compared to the general population.

Other studies have examined the relationship between the human genome and psychological factors, including personality. Despite the relatively small body of research concerned with the genetics underpinning central functioning, analysis indicates that the four subscales of mental toughness, challenge, control, commitment and confidence (Crust and Clough, 2005) and the Big 5 personality dimensions, neuroticism, extraversion, agreeableness, conscientiousness, and openness to experience, may be attributed to both genetic and non-shared environmental factors (Horsburgh et al., 2009).

Despite challenges in identifying individual genes involved in sporting success, studies have highlighted a limited number that appear to affect the psychological background impacting training and competition. Researchers have suggested that the serotonin transporter gene 5HTT may be linked with the ability to control emotion, and identified an association between the 5HTT polymorphism, neuroticism and stress, in athletes (Lippi et al., 2009; Petito et al., 2016). The literature also suggests that the brain-derived neurotrophic factor BDNF may impact perceived effort during aerobic activity; research by Oztasyonar (2017) identified that middle, and long, distance runners had a higher basal BDNF than sedentary participants and Ulucan (2016) speculated that, though the effect of BDNF is unclear, it may be one of the target molecules for successful sporting performance and warrants further investigation. The dopamine receptor gene (D4DR) appears to affect the dopaminergic system, involved in both motivation, arousal and risk-taking behaviour (Carpenter et al., 2011; Eichhammer et al., 2005). Whilst in a study by Çam et al. (2010) of high-risk sports athletes, openness to new experience scores were significantly different for DRD4 genotypes and highlighted the importance of future behavioural genetic studies to sport psychology.

Though many of the genes involved in endurance are not well understood, researchers have concluded that heritability has a considerable impact on performance potential, and athletes, elite or otherwise, may benefit from interventions, including training, injury prevent and nutrition, individualised according to their genotype.

2.3.5.3. Critical Appraisal

Whilst the ACE gene has received considerable attention with regards endurance, results have been inconsistent and further testing is warranted (Castilha, et al., 2018). In contrast, a lack of research exists comparing the individual genes, believed to impact psychological factors in endurance success, as outlined (BDNF, 5HTT, D4DR). This programme of research uses quantitative measures to identify relationships and enhance understanding of the relationship between genetics and endurance performance.

2.4. Psychophysiological Models of Endurance

It is widely acknowledged that humans have a large capacity of psychological resources to deal with challenges at many levels, but that it is not always possible to access such resources deliberately (Weger & Loughnan, 2013). So far, in the current thesis, psychological and physiological factors that relate to endurance performance of athletes have been described separately. By doing so, the fullness of the endurance athlete performance experience is restricted, therefore, Section 2.4 provides an overview of two interdisciplinary models that have been proposed to integrate the psychological and physiological mechanisms that limit endurance performance.

2.4.1. Mind over Matter

An athletes' mental state, and the mental strategies they utilise, have been shown to impact endurance performance (Gucciardi, 2017; Hanson et al., 2015; McCormick et al., 2015).

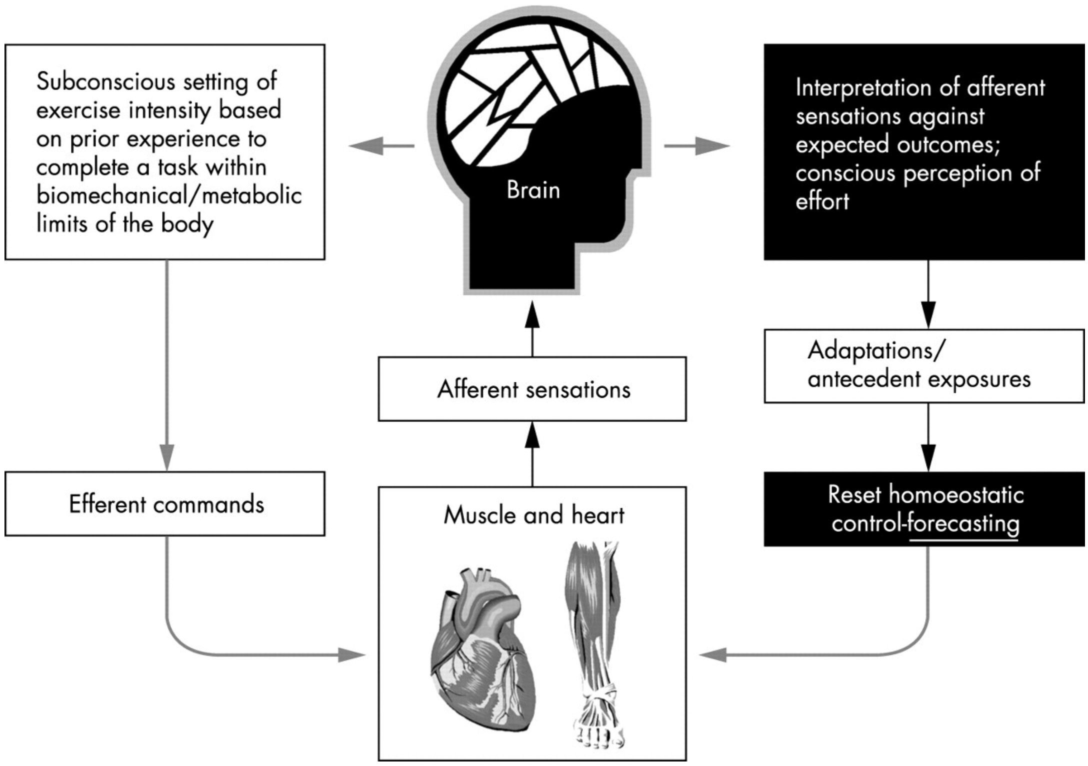
2.4.2. Central Governor Model

According to Noakes (2004; 2007), the widely held view that exercise performance is limited by chemical factors in the muscles is incorrect, and the muscular, *peripheral* fatigue model used to explain exercise tolerance, requires a re-think. Such peripheral fatigue is postulated to be in response to a failure of the heart, during maximal exercise, to supply sufficient oxygen to the muscles to avoid reaching skeletal muscle anaerobiosis, causing the accumulation of lactic acid, resulting in muscle fatigue (Noakes, 2004; 2007). Consequently, this peripheral, or *classical* model contends that homeostasis is relatively constant but during extreme aerobic exercise there is an inability to anticipate, and take the necessary actions to avoid, catastrophic metabolic failure. As a result, the peripheral model does not adequately explain the frequent ability of athletes to increase pace, near the end of competition, despite all available muscles having already been recruited and fatigued (Noakes, 2007, 2012).

In response, Noakes (2004) proposed the Central Governor Model (CGM), whereby sensory feedback of metabolites, the intermediate products of metabolic reactions to the brain, or spinal cord, actively regulate the recruitment of an appropriate numbers of muscle fibres to ensure exercise is completed safely. CGM predicts such control systems manage the number of motor units activated, to ensure homeostasis, irrespective of either exercise intensity or duration, and that the perception of fatigue is generated by the brain to ensure increasing discomfort causes exercise to cease in advance of homeostasis failure. According to the CGM model, during a race, a subconscious element of the athlete's brain sets the pace, based on the anticipation of the duration, and intensity of the event (Noakes, 2004). CGM therefore predicts marathon performance is set by the subconscious brain, to ensure the athlete makes it to the finish line, whilst retaining physiological homeostasis, and completes the distance with a degree of physiological reserve (Noakes, 2007). According to Noakes (2012) the pacing strategy of an athlete is the outcome of a comparison between the actual sensations of fatigue, a conscious epiphenomenon arising from the interpreting subconscious regulatory processes in the brain, interpreted as the rating of perceived exertion (RPE), and the expected level of fatigue, see Figure 2.6. Researchers suggest that the RPE may be set early on during exercise, as part of a feedforward control mechanism, provides the link between the physiological parameters impacted by exercise and the subsequent behaviours to maintain homeostasis, and is predictive of the duration of exercise to exhaustion (Crewe et al., 2008; Noakes, 2007).

A recent paper by Robergs (2017) has criticised the CGM, citing a lack of evidence, and insufficient provision of a precise and clear theoretical content to enable researchers to develop research methods and questions to support falsification. Whilst St Clair Gibson, Swart and Tucker (2017) propose the Integrative Governor Theory replacing the concept of a central governor in regulating activity with dynamic negative activity feedback as the general operational controller and homeostatic principles that underpin psychological and physiological drives and requirements. Furthermore, they suggest that research has been limited by a focus on central versus peripheral control mechanism models, and instead exercise performance is a result of 'weighting' psychological and physiological homeostatic drives (St Clair Gibson et al., 2017).

Figure 2.6 - *Relation between the Teleoanticipatory Governor Centre in the Brain and Perceived Exertion During Exercise (Lambert, Gibson, & Noakes, 2005).*

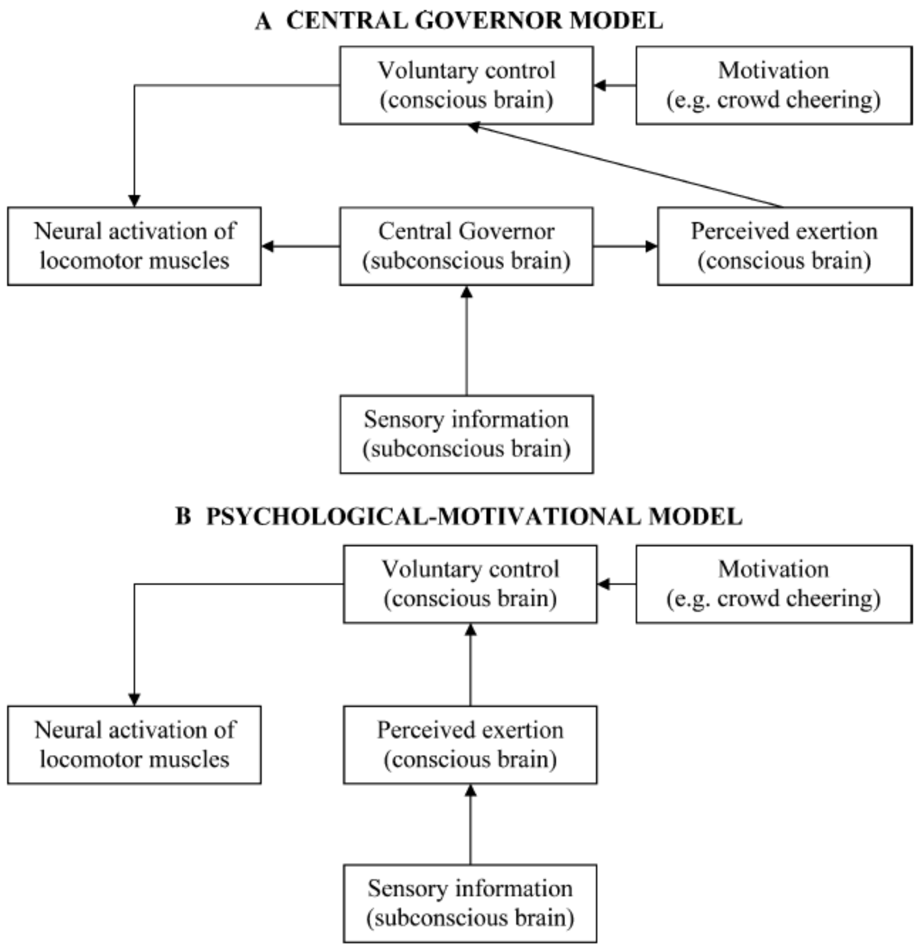


2.4.3. Psychobiological Model

Marcora (2008) has also challenged both the popular view that the length of aerobic exercise is limited by peripheral, or muscle fatigue, and furthermore the need for a central governor to deter the conscious brain through increased RPE, and a subconscious element that controls maximal neural recruitment of locomotor muscles, for a comparison see Figure 2.7 (Marcora, 2008).

According to the Psychobiological Model, which integrates both psychology and physiology, exhaustion, and disengagement from the task, occurs when either the maximum effort the individual is prepared to exert is reached, or perceived maximal effort is achieved, and continuation impossible (Marcora, 2008). In addition, mental fatigue, rather than cardiovascular, or muscular mechanisms, limits exercise tolerance by increasing the RPE leading to a subsequent reduction in self-paced endurance performance (Marcora et al., 2009; Pageaux, Lepers, Dietz & Marcora, 2014). Research findings report inhibitory tasks, that mentally fatigue participants, such as performing a stroop test (a measure of attention), in advance of endurance activities, increase RPE leading to early disengagement from physically challenging tasks (Marcora et al., 2009; Pageaux et al., 2014). McCormick et al. (2015) also concluded that in response to findings that mental fatigue limit endurance performance, psychological skills training is of benefit.

Figure 2.7 - *The Central Governor (a) and the Psychological-motivational (b) Models of Exercise Performance taken from Marcora, (2008)*



2.4.4. Implications for Research

Whilst both the CGM and the Psychobiological Model provide an integrated perspective, including psychological and physiological factors involved in endurance performance, the impact on perceived exertion, and its potential to limit aerobic activities, remains unclear and warrants further research exploration.

The current research programme quantitatively measures factors that may both impact endurance success, and interact with the perception of effort, including mental toughness, motivation, personality, running economy, stress hormones, lactate, heart rate, along with exercise intensity and duration. However, it is beyond the scope of this thesis, to directly test the validity of either the Central Governor Model, or the Psychobiological Model, and from the literature it remains unclear the measures required to adequately define, or distinguish between the two (Clough et al., 2002; Crewe et al., 2008; Eston, 2012; Hutchinson & Tenenbaum, 2006).

2.5. Summary and Aims of Thesis

Researchers have identified that athletic performance is likely to be underpinned by both psychological and physiological factors (Gucciardi, 2017; Marcora & Staiano, 2010; Mier et al., 2012). According to the literature: (a) mental toughness is an important, multidimensional, psychological construct impacting performance in sport (Gucciardi et al., 2016; Vaughan et al., 2017); (b) motivation energises and directs our sporting behaviour (Ryan & Deci, 2017); and (c), whilst research findings are inconclusive, personality dimensions appear to identify top performing athletes (Freund et al., 2013). However, there is a lack of research exploring the relationships between these psychological factors and endurance performance markers, including maximum oxygen uptake, lactate threshold and running economy, in ultra-marathoners.

Consequently, the aim of the current programme of research, is to provide an integrated understanding of the factors involved in endurance through quantifying, and comparing, psychophysiological factors. Psychological factors include mental toughness, personality and motivation, and physiological factors, include $\dot{V}O_{2max}$ scores, pain tolerance and threshold, stress hormone, lactate threshold, running economy, and selected genes, that (a) affect success in the ultra-marathoner, and (b) affect the limits of aerobic fitness. Indeed, according to Mauger (2013) exercise induced pain may inform the conscious decision whether to increase or decrease effort and contribute to fatigue during exercise performance.

The measures and research design detailed in Section 3 were based on the above literature review to ensure an interdisciplinary view of factors previously identified, or potentially viable, affecting successful endurance performance. These psychological and physiological factors were subsequently measured in both competition, and controlled laboratory conditions, in non-elite ultra-marathon runners, and non-ultra-marathon runners.

CHAPTER THREE

3. Experimental Design and Methodology

3.1. Overall Experimental Design

Studies 1 and 2 were cross-sectional and aimed to identify differences between ultra-marathoners and non-ultra-marathoners, whilst Field Study 3 was repeated measures, measuring race participants at two time points. A quantitative, interdisciplinary approach was adopted for all studies to identify significant differences between participant groups and correlations between psychological and physiological factors.

3.2. Participants

3.2.1. Participant Number

Sample size was determined based on a power calculation by Montgomery et al. (1988) into pre and post–training performance in relation to the ACE gene polymorphism. Based on a pre-training SD = 6.2, and a post training (II genotype) SD = 25.2, d = 1.2, alpha = 95%, $p < .05$ or 5% level, power at 0.85, a minimum participant number was calculated as 15 (Cohen, 1988). The sample size estimation was used to inform how many participants were the minimum number for the MANOVA's and subsequent ANOVA's performed in Studies 1 and 2, and the paired-sample t-tests performed in Study 3 (see section 3.6.1).

3.2.2. Participant Consent and Screening

All participants were provided with a written description of the study and consent forms, prior to taking part. Informed consent was provided in advance of testing and participants were made aware of their right to withdraw at any point. Participants completed a "Psychology & Physiology in Endurance Health Questionnaire v1-0" and the "Psychology & Physiology in

Endurance Training Questionnaire v1-0" (See Appendix 8.1), to confirm suitability. Any participants considered unhealthy, or with known cardiovascular related issues, were excluded from participating in the study. This included, but was not limited to, suffering from any kind of illness or infection – such as upper respiratory tract infections, or carrying any form of injury – such as sprained ankles or broken bones. No inducements were offered in this study.

3.3. Psychological Measures

3.3.1. Mental Toughness

The Mental Toughness Questionnaire 48 (MTQ48) (Crust & Clough, 2005) was completed by all participants. Permission for use of the MTQ48 was granted by the authors. The 48-item instrument, included in Appendix number 8.2.2, is comprised of four subscales measuring confidence (abilities and interpersonal), commitment, challenge and control (life and emotional). Each question is answered on a 5-point Likert scale - where 1 is equal to strongly agree and 5 is equal to strongly disagree. Example questions include rating a number of statements including "I usually find something to motivate me" and "I generally feel in control". The scale is considered to have sufficient internal reliability: Cronbach's alpha for individual subscales range from 0.71-0.79, mental toughness 0.89 (Crust & Clough, 2005).

As there have been some concerns regarding the conceptualisation that underpins the content of the MTQ48, partly due to the question of lack of independent scrutiny of the underlying factor structure raised by Sheard et al. (2009), the Sports Mental Toughness Questionnaire (SMTQ) was also completed for Study 1 (See Appendix 8.2.1). The 14-item SMTQ comprises of three subscales which assess confidence, constancy and control using 14 items and a 5-point Likert scale. Each question is answered on a 5-point Likert scale - where 1 is equal to strongly agree and 5 is equal to strongly disagree. SMTQ was discarded for Studies 2 and 3, due to the high standard deviations and the strong associations with the MTQ48 (in Table 4.1), that provided confidence in the latter as an instrument.

3.3.2. Personality

Each participant completed the Big 5 Personality Inventory (Kaiseler et al., 2012). The inventory consists of 44-items used to measure the five dimensions of personality on a 5-point rating scale from 1- disagree strongly, to 5 – agree strongly. The dimensions have suitable internal reliability: Cronbach's alpha: 0.71 (Openness), 0.77 (Agreeableness), 0.79 (Neuroticism), 0.81 (Conscientiousness), and 0.82 (Extraversion) (Kaiseler et al., 2012). Example items include rating a number of statements including "I am a person who is talkative", "I am a person who tends to find fault in others", "I am someone who is reserved". The Big 5 Personality Inventory questionnaire is freely available for research purposes (See Appendix 8.2.3).

3.3.3. Motivation – Self-determination Theory

The General Causality Orientation Scale (GCOS) was developed as part of the Causality Orientation Theory, a mini-theory of SDT, to assess the strength of three different orientations towards the environment and one's own motivation (Ryan & Deci, 2017). GCOS was utilised to measure enduring motivational orientation, by testing 36 items, that describe typical, social or achievement-oriented situations (e.g., job applications, relationships with friends) with responses indicating either an autonomous, controlled, or impersonal type of motivation. Examples of the questions asked (see Section 8.2.4) include: "You have been offered a new position in a company where you have worked for some time. The first question that is likely to come to mind is: - What if I can't live up to the new responsibility? OR Will I make more at this position? OR "I wonder if the work will be interesting"; another question asks "You have a school-age daughter. On parents' night the teacher tells you that your daughter is doing poorly and doesn't seem involved in the work. You are likely to: - Talk it over with your daughter to understand further what the problem is OR Scold her and hope she does better. OR Make sure she does the assignments, because she should be working harder.” Autonomy (Deci & Ryan, 1985) is defined as “A person high in *autonomy* orientation tends to display greater self-initiation, seek activities that are interesting and challenging, and take greater responsibility for his or her own behaviour”, *control* is defined as ‘Assesses the extent to which a person is oriented toward being controlled by rewards, deadlines, structures, ego-involvements, and the directives of others.”, *impersonal* is defined as ‘The extent to which a person believes that attaining desired outcomes is beyond his or her control and that achievement is largely a matter of luck or fate.” .

The SDT GCOS questionnaire is freely available for research purposes. (See Appendix 8.2.4).

3.4. Physiological Measurements

3.4.1. Aerobic Fitness - $\dot{V}O_{2max}$ Test

All participants performed an incremental exercise test to volitional fatigue on a motorised treadmill (HP Cosmos Pulsar, Germany), in order to determine maximum oxygen uptake. For Study 1, a running speed of 12 km/h was utilised throughout the test for all participants, while after each one-minute interval the treadmill gradient was increased by 1%. For Study 2, the gradient remained constant whilst the running speed increased by 1 km/hr for all participants, from 12 km/hr, after each one-minute interval. Oxygen uptake was determined throughout exercise using an on-line gas analysis system (Cosmed Quark CPET, Italy) whilst heart rate was measured via a portable short-range telemetry device (Polar, Sweden). In Studies 1 and 2, for a limited number of participants (9 of the 10 non-ultra-marathoners in Study 1), the ratio of oxygen inhaled versus CO_2 exhaled, known as the Respiratory Exchange Ratio (RER), did not exceed 1.15 and the predicted maximum heart rate (MHR), based on 220 minus age at time of test, was not exceeded. The highest $\dot{V}O_2$ (ml/min/kg) value will therefore be referred to as the $\dot{V}O_{2peak}$ (ml/min/kg) and taken as a record of the participants' endurance.

3.4.2. Rating of Perceived Exertion

Rating of Perceived Exertion (RPE) was recorded as a means to predict aerobic capacity (Crewe et al., 2008; Eston, 2012). The most widespread method of quantifying the RPE in order to provide subjective feedback of exercise intensity, is the Borg 6-20 scale (Borg, 1982; Heath, 1998). RPE integrates both psychological and physiological factors to predict exercise capacity and appears to predict changes in pace and pacing strategy adopted (Eston, 2012). The RPE was recorded every minute throughout all exercise testing.

3.4.3. Running Economy

Running economy (RE) was recorded as the submaximal oxygen ($\dot{V}O_2$) at a pre-defined running velocity, typically 16km/hr (Barnes & Kilding, 2014), during the incremental exercise test on a motorised treadmill to measure $\dot{V}O_{2max}$ (Section 3.4.1). As a number of participants, in the low aerobic group, failed to reach this running velocity on the $\dot{V}O_2$ test, 15km/hr was chosen as the speed to record oxygen consumption as a means to predict exercise capacity.

3.4.4. Pain Tolerance/Threshold

Pain threshold and tolerance was measured using an ice bath (Samuel & Ebenezer, 2013). Participants were asked to place their non-dominant hand, up to the first wrist crease, into a crushed-ice slurry at zero degrees centigrade. Pain threshold was the time taken until the participant first verbalised pain, and pain tolerance was the time taken until the participant withdrew their hand from the ice. Participants were not informed that there was a 5-minute time limit on the pain test after which the participant was told to remove their hand as the test had finished.

3.4.5. Lactate Inflection Point

Capillary blood lactate concentration was measured using a portable lactate analyser (Lactate Pro analyser by Arkray Inc, Kyoto, Japan), that can measure lactate from 0.3ul of blood and results are available within 15 secs. The participant stepped off the treadmill at 3-minute intervals, the blood samples were taken, prior to returning to the treadmill and running speed increased by 1 km/hr. The blood was capillary blood taken using a sterile lancet and deposited onto a lactate pro strip inserted into the portable analyser.

3.4.6. Stress Hormones

Salivary, and blood cortisol are tightly correlated in response to acute exercise (Tanner et al., 2013). Saliva was identified as a convenient means of collecting and quantifying cortisol and testosterone levels and as a biomarker for physiological stress (Tanner et al., 2013). Measurement of salivary cortisol and testosterone was taken immediately prior to, and following, competition as per Crewther et al. (2013), and analysed using Salimetrics, Expanded Range, High Sensitivity Salivary, Enzyme ELISA 96 well plate immunoassay kits for both cortisol and testosterone.

Assay was performed following manufacturer's instructions:

- Cortisol in standards and samples compete with cortisol conjugated to horseradish peroxidase for the antibody binding sites on a microtiter plate.
- After incubation, unbound components are washed away.
- Bound cortisol enzyme conjugate is measured by the reaction of the horseradish peroxidase enzyme to the substrate tetramethylbenzidine (TMB). This reaction produces a blue colour. A yellow colour is formed after stopping the reaction with an acidic solution.
- The optical density is read on a standard plate reader at 450 nm. The amount of cortisol enzyme conjugate detected is inversely proportional to the amount of cortisol present, in the sample.

3.5. Blood Extraction and Analysis

DNA was extracted from 5 ml blood samples, taken using the single venepuncture method from a prominent antecubital vein in the participants forearm, and collected into an EDTA Vacutainer tube as described in Collins et al. (2004). White blood cells were subsequently extracted and subsequently stored in 1ml of RNA later, and frozen in solution, and later genetic analysis.

3.5.1. Angiotensin Converting Enzyme (ACE) Gene Quantification

DNA was extracted from 4.5 ml of EDTA whole blood extracted from a prominent antecubital forearm vein. Blood genomic DNA was quantified using a commercially available GenElute Blood Genomic DNA kit (Sigma Aldrich, USA) as per manufacturer's instructions. Each sample was genotyped for the ACE gene allele insertion (I)/deletion (D) polymorphism, using PCR with gene specific primers (Rigat, Hubert, Corvol & Soubrier, 1992). Primers were designed that flank the insertion sequence on intron 16 of the ACE gene (sense primer 5'-CTGGAGACCACTCCATCCTTTCT-3' and antisense primer 5'-GATGTGGCCATCACA TTCGTCAGAT-3'). PCR was performed in a 25-µl reaction containing Amplitaq Gold PCR Mastermix (Applied Biosystems) as per manufacturer's instructions. All reactions were performed in a Techne TC-512 gradient cycler. Reaction conditions were as follows, initial denaturation at 95°C for 5 minutes, followed by 40 cycles of denaturation at 95°C for 30 seconds, annealing at 56°C for 30 seconds, and extension at 72°C for 30 seconds. A final extension step was employed at 72°C for 7 min before being held at 4°C. The amplified products were separated by electrophoresis on a 2% agarose/1X TAE (Tris, Acetic acid, EDTA) gel containing SYBRSafe DNA gel stain (Invitrogen). PCR products were subsequently visualised using a under UV light and images captured via an InGenius gel documentation system (Syngene). The PCR resulted in the amplification of a 190 bp amplicon in the absence of the insertion (DD) and a 490 bp amplicon in the presence of the insertion (II). PCR reactions in which 2 bands were present at 190 bp and 490 bp were classified as (ID) heterozygotes. Previous studies in which this genotyping technique has been employed, report misclassification of ID heterozygotes as DD due to preferential amplification of the smaller D allele. Therefore, in order to prevent mistyping and to verify the DD samples, any sample found to be DD was subjected to a second round of PCR with an insertion specific primer set (Sense 5'-TGGGACCACAGCGCCCGCCACTAC-3' and antisense 5'-TCGCCAGCCCTCCCATG CCCATAA-3').

3.5.2. Genetic Testing for the 5HTT, BDNF and D4DR Genes

Blood samples were taken using the single venepuncture method from the participants forearm and collected into an EDTA Vacutainer tube as described in Collins et al. (2004). Addition of Histopaque-1077 (Sigma) allowed for the separation and subsequent isolation of peripheral blood mononuclear cells (PBMCs) as per manufacturers protocol. PBMCs were stored in RNAlater (Invitrogen) for downstream processing. RNA was extracted from PBMCs via the TRIZOL (Invitrogen) method, and this was subsequently quantified via the NanoDrop Spectrophotometer System (ThermoFisher). All RNA samples were DNase treated, with DNaseI to remove any contaminating genomic DNA. First-strand cDNA was prepared from exactly 250 ng of RNA using the Superscript II Reverse Transcriptase kit (Invitrogen), with 200 μg/μl random hexamers used to reverse transcribe the RNA. PCR Primers were designed in house against published sequences for Ubiquitin C (UBC) (Sense 5'-CTGGAAGATGGTCGTACCCTG-3' and Antisense 5'-GGTCTTGCCAGTGAGTGTCT-3'), Brain Derived Neurotrophic Factor (BDNF) (Sense 5'-GGCTATGTGGAGTTGGCATT-

3' and Antisense 5’-CTTCGAGGCCTTCGTTTTG-3’), Serotonin Transporter (5HTT) (Sense 5’-ACGGAGTTCTACAGAAGGTTGT-3' and Antisense 5’-ATAGAGTGCCGTGTGTCAT CT-3’), and Dopamine D4 Receptor (D4DR) (Sense 5’-CTGCCGCTCTTCGTCTACTC -3' and Antisense 5’-ATGGCGCACAGGTTGAAGAT -3’).

PCR was performed in a 25 µl reaction containing Amplitaq Gold PCR Mastermix (Applied Biosystems) as per manufacturer’s instructions. All reactions were performed in a Techne TC-512 gradient cycler. Exactly 2 µl of cDNA was used in each reaction.

The genes were amplified by 32 cycles of 95°C for 30 s, 60°C for 30 s, and 72°C for 20 s and, finally, an extension step at 72°C for 10 min. 32 cycles was chosen as this was within the exponential phase for each primer set. Following PCR exactly 10µl of the PCR products were separated by electrophoresis on a 2% agarose/1X TAE (Tris, Acetic acid, EDTA) gel containing SYBRSafe DNA gel stain (Invitrogen). PCR products were subsequently visualised using a under UV light and images captured via an InGenius gel documentation system (Syngene).

Semi quantitative densitometry analysis was performed on each of the PCR products from each participant sample using ImageJ’s Gel Analysis function. Briefly a .TIF image of our PCR gel was imported into ImageJ and converted to 8-bit grey-scale image. A rectangular selection was placed over each PCR band, and a profile plot representing the relative density of the rectangular selection was obtained.
Data was exported to MS Excel for analysis. Density of UBC was used as a standard and given a value of 1, density of all other gene products was calculated relative to the calculated density for UBC expression.

3.6. Statistical Analysis

All analysis was performed using Statistical Package for the Social Sciences Version 24 (SPSS Inc. Chicago, IL, USA). Data was screened for outliers, checked for equality of variance and normality.

3.6.1. Comparative Statistics

Study 1: Two multivariate analysis of variance (MANOVA) tests were performed to identify whether the two groups, ultra-marathoners and non-ultra-marathoners differed significantly based on their psychological measures, including mental toughness and personality, and physiological measures, $\dot{V}O_{2peak}$ score and training (see power calculation performed, section 3.2.1). Where the MANOVA tests were statistically significant, post-hoc ANOVAs were performed on the dependent variables. A Chi-Square test for association was performed to test for association between the two categorical variables, ultra-marathon group and having the ACE gene allele – the latter being either II (homozygous insertion), ID (heterozygous) or DD (homozygous deletion). Pearson Product Moment Correlation coefficients were utilised to determine the strength and direction of linear relationships between the physiological measures and the physiological measures.

Study 2: Multiple multivariate analysis of variance (MANOVA) tests were performed to identify whether the three groups, ultra-marathoners, aerobic and low aerobic differed significantly based on their psychological measures, including mental toughness, personality, motivation, pain, RPE, and physiological measures, including $\dot{V}O_{2peak}$ score, lactate inflection point, selected genes (see power calculation performed, section 3.2.1). Where the MANOVA tests were statistically significant, post-hoc ANOVAs were performed on the dependent variables. The effect size, emphasising the size of the difference, was calculated using η_p^2 (.01=small; .06=medium; .14=large) (Nakagawa & Cuthill, 2007).

Pearson Product Moment Correlation coefficients were calculated to determine the strength and direction of linear relationships within, and between the physiological measures and the physiological measures. Paired-sample t-tests were utilised to identify differences in salivary cortisol prior to and following exercise.

Study 3: Paired-sample t-tests were utilised to compare differences in stress hormones, cortisol and testosterone prior to and following completion (see power calculation performed, section 3.2.1). Pearson Product Moment Correlation coefficients were utilised to determine the strength and direction of linear relationships between the psychological, and physiological measures of mental toughness, personality, age, and levels of hormone change.

CHAPTER FOUR

4. Study 1: Psychological and Physiological Factors that Influence Performance in Ultra-Marathon Runners

Abstract

Psychological and physiological factors were examined as part of a cross-sectional, interdisciplinary study, to ascertain what influenced performance in ultra-marathoners and non-ultra-marathoners. 20 participants were included all male (M age = 35.26, SD = 5.37), 10 had previously taken part in an ultra-marathon and 10 had neither trained for, nor entered, such an event. Participants completed psychological tests for mental toughness and personality, including the Mental Toughness Questionnaire 48, the Sports Mental Toughness Questionnaire, and the Big 5 Personality Inventory, along with physiological assessment of $\dot{V}O_{2peak}$ scores, and the ACE gene allele. There was a significant difference between groups on $\dot{V}O_{2peak}$, however there were no differences between ultra- and non-ultra-marathoners on mental toughness and personality scores. Furthermore, the ACE gene allele, usually associated with physical endurance, was not present in one group more than the other. There were significant positive correlations, for all participants, between $\dot{V}O_{2peak}$ scores and the personality trait conscientiousness ($p < .01$), and between $\dot{V}O_{2peak}$ and commitment scores ($p < .05$). Together these findings suggest that ultra-marathoners may achieve higher levels of endurance as a result of physiological adaptions following increased training regimes, and differences in psychological characteristics neither identify ultra-marathoners nor preclude participation in an endurance event.

4.1. Introduction

The last decade has seen considerable growth in both the quantity of endurance events and the number of entrants, at both elite and non-elite levels (Baumann et al., 2014; Hurdiel et al., 2018; Wardenaar et al., 2018; Wortley & Islas, 2011). Increased media attention, mass participation, and the popularity of elite sports-men and women has led to a greater interest in athletic performance and an awareness that success is likely to be underpinned by both psychological and physiological factors (Gucciardi et al., 2016; Montgomery et al., 2011). Top-level sports men and women, reaching the highest echelons of competition, are comparable in terms of their training and aerobic fitness, with success reliant on their psychological ability to manage stress, retain focus, clear thinking, and maintain consistency (Jones et al., 2002).

Over the last decade researchers have shown an increased interest in endurance sports. This is evident in a growing body of literature which has investigated: the trends in participation and performance in ultra-marathons (Fonseca-Engelhardt et al., 2013), the links between psychological parameters and endurance performance (Mccormick et al., 2015; Schüler, Wegner, & Knechtle, 2014), and the effect of physiological parameters, such as exercise training, anthropometric features, on performance in ultra-marathoners (Baumann et al., 2014; ; Knechtle, 2012; Tan et al., 2017). Collectively, the findings from these studies show an association between psychological and physiological parameters, and endurance performance, however little attempt has been made to quantitatively measure, and compare, the predictors of optimum performance in ultra-marathoners. Furthermore, interdisciplinary research linking psychological and physiological evidence together has been scant and, for studies that have, it is difficult to be convinced by the conclusions based on the research methodologies adopted.

A more comprehensive understanding of psychological moderators described below, including mental toughness, personality and genetic predispositions in endurance events may enable coaches and sports scientists to provide improved support for new, and existing, athletes to optimise performance.

The Big 5 personality dimensions: neuroticism, extraversion, agreeableness, conscientiousness, and openness to experience are used as a common framework for investigating personality (Kaiseler et al., 2017), with researchers indicating that higher-order personality dimensions influence an athlete's ability to cope with pressure (Allen et al., 2011). However, a recent study ascertained that although athletes scored higher than non-athletes for conscientiousness, no statistically significant differences were identified between groups for the other four, of the Big 5, traits (Malinauskas et al., 2014). Analysis of the findings suggest that personality may be an influencing contextual factor in sport (Kaiseler et al., 2012), whilst the effect personality has on appraisal, coping effectiveness and the ability to handle stress without a related performance degradation in endurance remains largely unexplored. Supporting research by Horsburgh et al. (2009) also demonstrated there are strong correlations between Big 5 variables and mental toughness, and importantly that both are heritable.

There is widespread consensus amongst researchers that mental toughness is one of the most important, multidimensional, psychological constructs related to performance excellence in sport (Connaughton et al., 2008; Perry et al., 2013; Gucciardi et al., 2016; Thelwell et al., 2010). However, a number of concerns have been raised regarding mental toughness: its definition and underlying conceptual framework; the assumption that elite athletes are mentally tough; a lack of objective measures (Crust, 2008); caution regarding its multidimensionality;

and challenges regarding its permanence over time and across situations (Gucciardi et al., 2014).

Despite the conceptual challenges to mental toughness and its measurement validity, as discussed in Chapter 2 (Section 2.2.1), mental toughness remains highly valued by coaches and athletes alike. According to the widely accepted view by researchers, an athlete that has mental toughness exhibits an advantage over opponents by enabling the individual to cope better with the demands that sport places on them, whilst maintaining consistency in determination, focus and having control whilst under pressure (Connaughton et al., 2008; Gucciardi & Gordon, 2013; Gucciardi et al., 2016; Jones et al., 2002; Perry et al., 2013; Thelwell et al., 2010). A conceptual model developed by Crust and Clough (2005) defined mental toughness as a trait-like dimension of personality, made up of four psychological attributes, control, commitment, challenge and confidence (4Cs). Despite concerns regarding the underlying structure (Sheard et al., 2009), research using the Mental Toughness Questionnaire (MTQ48) showed a positive correlation between mental toughness and, physical endurance and the tolerance of physical pain (Crust & Clough, 2005). A recent study by Gucciardi et al. (2016) tested Australian footballers using a series of performance tests, including a 20-metre sprint, agility run, vertical jump, and multistage shuttle run, and supported the view that mental toughness predicted behavioural perseverance. They further encouraged, for completeness, that future research should include direct measurements of aerobic fitness, in the laboratory, through quantifying maximal oxygen consumption.

Maximal oxygen consumption ($\dot{V}O_{2max}$) is a measure of aerobic fitness and is frequently quantified in runners using a treadmill test of increasing workload and yields a standard means to assess overall physical fitness. $\dot{V}O_{2max}$ provides a representation of the ability of the body to deliver oxygen to working muscles during exercise (Tsigilis, 2005), including running (Haff & Dumke, 2012), and a measure of the maximum rate at which oxygen is consumed during oxidative phosphorylation.

Human genetic identity is likely to be a strong factor in endurance success, with a large number of phenotypes, including heart and lung capacity, musculature and tendon elasticity influencing performance in sport (Puthucheary et al., 2011; Valdivieso et al., 2017). Horsburgh et al. (2009) identified the average heritability for any given personality trait, including MT, as 50%, and researchers have confirmed an estimated heritability for gains in aerobic capacity from endurance training as also 50% and suggested genotype-tailored training interventions (Barry, Church, & Blair, 2010; Sarzynski et al., 2017). Previous studies have established that numerous, individual genes can impact sporting performance (Lippi et al., 2009; Puthucheary et al., 2011), and even potentially, through gene doping, illegally improve the likelihood of successful competition (Gronde, Hon, Haisma, & Pieters, 2013).

One such earlier, candidate gene study, by Montgomery et al., (1998) identified the insertion allele of the gene encoding angiotensin-converting enzyme (ACE) as being associated with endurance performance amongst both mountaineers and elite endurance athletes. Montgomery et al., (1998) suggested that the presence of the gene alone does not necessarily indicate superior performance, but rather that it must be coupled with appropriate training for any beneficial effect to be present. Subsequent studies identified the insertion allele frequency as being higher in endurance athletes, including ultra-distance swimmers, long-distance cyclists, and Ironman triathletes (Montgomery et al., 2011). In contrast, others, such as Ash et al., (2011) have demonstrated that the genomic analysis of world-class Kenyan and Ethiopian athletes, have not reported an increased presence of the ACE gene polymorphism when compared to the general population.

To date, the primary focus of research in the field of mental toughness and personality in sport has been on elite athletes, and many of the studies have been qualitative (Anthony et al., 2016). Relatively little attention has been directed towards quantitative research methodologies to identify both the psychological and the physiological factors, and their interaction, that predict performance in ultra-marathoners. The present study contributes to current understanding of endurance athletes by comparing ultra-marathoner runners with non-ultra-marathon runners using $\dot{V}O_{2max}$ scores, mental toughness, Big 5 personality dimensions and the ACE gene allele to identify if significant differences are present. Correlations were also calculated to identify relationships between psychological and physiological attributes. This was the first study of this nature to quantify, and compare, both psychological and physiological factors, between ultra-marathoners and non-ultra-marathoners. Three hypotheses were tested: it was hypothesised that: (a) there will be no statistically significant differences between the mental toughness, and personality scores from questionnaires completed by ultra-marathon runners and non-ultra-marathon runners; (b) there will be no significant differences in the measurements of the $\dot{V}O_{2peak}$, and training volume between ultra-marathon runners and non-ultra-marathon runners; and finally (c), there will be no significant differences in the incidence of the allele of the ACE gene between ultra-marathon runners and non-ultra-marathon runners.

4.2. Methods

4.2.1. Participant Characteristics

Twenty male participants aged between 20-45 (mean age 35.26 ± SD 5.37) were selectively allocated to one of two groups based on previous competitive race participation. Those participants who had previously completed an ultra-marathon event were allocated to the ultra-marathon group, whilst those with no experience were allocated to the non-ultra-marathon group. The ultra-marathon group trained aerobically between 5.5 and 15 hours per week (mean hours trained 9.2, ± SD 2.96), though largely attributed to running, activity included cycling and swimming. The non-ultra-marathon group trained aerobically between 0 and 3 hours per week (mean hours trained 1.58 hours, ± SD 0.91).

4.2.2. Experimental Design

Ulster University Research Ethics Committee (UUREC) granted approval for this study (REC.13.0182). Human tissue was sampled, tested and stored in accordance with the Human Tissue Act (HTA) 2004.

A cross-sectional design was adopted to quantify the psychological and physiological differences between ultra-marathoners and non-ultra-marathoners. A recruitment email was distributed to participants who had previously completed an ultra-marathon event, and office workers who had not previously trained for, or taken part in such races. An ultra-marathon was defined as a running event exceeding the classical marathon distance of 42.20 km) in line with existing research and often taking place over 50km, 100km, or longer, as part of multi-day events.

4.2.3. Psychological Measures

Mental Toughness

Mental toughness was measured using the Mental Toughness Questionnaire (MTQ48) (Clough et al., 2002) and the Sports Mental Toughness Questionnaire (SMTQ) (Sheard et al., 2009). A detailed description can be obtained by referring to Methodology Section 3.3.1.

Personality

Personality was measured using the Big 5 personality inventory (Kaiseler et al., 2012). A detailed description can be obtained by referring to the Methodology Section in 3.3.2.

4.2.4. Physiological Measures

Maximum Oxygen Uptake ($\dot{V}O_{2max}$ Test)

Maximum oxygen uptake was measured using an incremental exercise on a motorised treadmill, increasing the gradient after each one-minute interval. A detailed description can be obtained by referring to Methodology Section 3.4.1.

Angiotensin Converting Enzyme (ACE) Gene Quantification

Blood genomic DNA was genotyped for the ACE gene allele insertion (I)/deletion (D) polymorphism, using the polymerase chain reaction (PCR) method with gene specific primers as previously described by Rigat et al. (1992). A detailed description can be obtained by referring to Methodology Section 3.5.1.

4.2.5. Data Analysis

During analysis, one participant in the non-ultra-marathon group, was excluded from further data analysis due to excessive training levels, along with completion of a number of marathons. Descriptive statistics were therefore calculated on data from the remaining 19 volunteers (age 35.26 ± 5.37), 10 in the ultra-marathon and 9 in the non-ultra-marathon group.

4.2.6. Learning and Development

General areas of learning and development for the successful completion of Study 1 included: (1) recruitment of participants, including communication, sharing and completion of health and training questionnaires using SurveyMonkey created for this research; (2) ethics committee submission and revision; (3) design and following of research protocol; (4) collection and organisation of data; (5) creation and usage of health and training questionnaires.

Specific areas of learning and development included: (1) maximal oxygen uptake testing; (2) SPSS data analysis; (3) analysis and calculation of MTQ48 and Big 5 scores; (4) performance of wet lab analysis of ACE gene polymorphism (see Section 3.5.1).

4.3. Results

4.3.1. Psychological Measures

The differences between the two groups for MTQ48 and the Big 5 dimensions, Table 4.1, were not statistically significant, $p > .05$; Wilks' $\Lambda = .208$; $\eta_p^2 = .79$.

Table 4.1- *Descriptive Data for Psychological Scores in the Ultra-marathon (n = 10) and Non-ultra-marathon (n = 9) Groups*

	Ultra-marathoners		Non-Ultra-marathoners	
	Mean	SD	Mean	SD
SMTQ - Confidence Score	18.20	3.22	17.78	2.28
SMTQ - Constancy Score	11.50	0.97	12.00	1.12
SMTQ - Control Score	11.60	2.88	11.33	3.00
SMTQ - Composite Scores	41.30	5.33	41.11	4.11
MTQ48 - Challenge Score	4.05	0.42	4.17	0.31
MTQ48 - Commitment Score	4.05	0.40	3.89	0.42
MTQ48 - Control Score TOTAL	3.71	0.35	3.69	0.60
MTQ48 - Control Score - Emotion	3.41	0.41	3.40	0.64
MTQ48 - Control Score - Life	4.01	0.55	3.98	0.59
MTQ48 - Confidence Score TOTAL	3.68	0.44	3.83	0.29
MTQ48 - Confidence Score Abilities	3.74	0.54	3.94	0.42
MTQ48 - Confidence Score Interpersonal	3.58	0.50	3.67	0.48
MTQ48 - Total Mental Toughness Score	3.84	0.32	3.86	0.34
Big 5 - Extraversion	3.26	0.54	3.63	0.48
Big 5 - Agreeableness	4.07	0.45	3.96	0.54
Big 5 - Conscientiousness	4.04	0.51	4.10	0.66
Big 5 - Neuroticism	2.17	0.57	2.01	0.39
Big 5 - Openness	3.52	0.50	3.50	0.50

4.3.2. Physiological Measures

The differences between the ultra-marathon and the non-ultra-marathon group on the combined dependent variables, $\dot{V}O_{2peak}$ and training volume (see Table 4.2), were statistically significant ($F(2, 16) = 28.035$, $p < .001$; Wilks' $\Lambda = .222$; $\eta_p^2 = .78$).

Follow-up univariate ANOVAs showed that there were statistically significant differences in: $\dot{V}O_{2peak}$ measures ($F(1, 17) = 226.685$, $p < .05$; $\eta_p^2 = .23$) and, hours training ($F(1, 17) = 274.801$, $p < .001$; $\eta_p^2 = .76$) recorded between the ultra-marathon running group, and the non-ultra-marathon group.

Table 4.2 - *Descriptive Data for Training and $\dot{V}O_{2peak}$ Scores in the Ultra-marathon (n=10) and Non-ultra-marathon (n=9) Groups*

	Ultra-marathoners			Non-Ultra-marathoners		
	Mean	SD	N	Mean	SD	N
Training (hours)	9.2	2.96	10	1.58	.92	9
$\dot{V}O_{2peak}$	58.84	5.94	10	51.92	7.3	9

A Chi-Square test was calculated (see Table 4.3) to examine the association between being in the ultra-marathon running group and having the ACE gene allele – the latter being either II (homozygous insertion), ID (heterozygous) or DD (homozygous deletion). There was no significant association between groups and the presence of the ACE gene allele, X_2 (2, N= 19) = 0.57, p = 0.75.

Table 4.3 - *Participant ACE Gene Alleles from Ultra-marathon Runners and the Non-Ultra-marathon Group*

ACE Gene Allele	Ultra-marathoners Number participants with allele	Non-Ultra-marathoners Number participants with allele
DD	3	2
ID	6	5
II	1	2

There were positive correlations in all participants between measures for: (a) $\dot{V}O_{2peak}$ and Big 5 Conscientiousness $r(7) = .53$, $p < .05$; (b) $\dot{V}O_{2peak}$ and MTQ48 - commitment $r(7) = .66$, $p < .005$); and (c) a medium positive correlation for $\dot{V}O_{2peak}$ and SMTQ Composite $r(7) = .49$, $p < .05$.

4.4. Discussion

The aim of Study 1 was to identify psychological and physiological differences between ultra-marathoners and non-ultra-marathoners. From the findings, it can be suggested that ultra-marathoners have a higher $\dot{V}O_{2peak}$ than non-ultra-marathoners, this appears to be as a result of a significantly higher volume of training rather than the psychological factors measured. The results of this study support the idea that neither mental toughness, personality, nor the status of the ACE gene allele, preclude participation in ultra-marathon events. Another finding is that across all participants there was a strong relationship between $\dot{V}O_{2peak}$, and both conscientiousness and commitment traits of personality.

In contrast to earlier research, an implication of this study is that ultra-marathoners are not identifiable by their mental toughness or their personality traits (Crust et al., 2005; Jones et al., 2002; Kaiseler et al., 2017). Though concerns have been raised around the MTQ48 regarding the underlying structure (Sheard et al., 2009), none have been raised with regards to the validity of the SMTQ, or the Big 5 Personality Inventory. Analysis of the data therefore suggests that mental toughness is not a factor in successful completion of endurance events, and a lack of significant differences in personality scores between the two groups indicates that an ultra-marathoner is similar in personality to a non-ultra-marathoner participant. However, a possible study limitation is that it is possible, that the SMTQ, MTQ48 and Big 5 Personality Inventory questionnaires fail to capture a contextual element only present within the confines of an ultra-endurance race, or related training. Furthermore, according to Gucciardi and Gordon (2013) mental toughness may not be a holistic concept and should not be viewed in contextual isolation. Crust (2008) suggests that the current limitation of studies is the ignorance of contextual differences. The failure to identify ultra-marathoners as a result of mental toughness, and a limitation of this research may, in part, be an issue of context. Mental toughness may be specific to an environment or situation, and ignorance of this contextual factor may lead to contradictory results (Crust, 2008, 2008a ; Gucciardi, 2017; Gucciardi & Gordon, 2013). There are also risks associated with (1) the assumption that mental toughness and success, in this case measured by maximal oxygen uptake, are strongly co-dependent, (2) that mental toughness is an indicator of superior athletic ability rather than the capacity to overcome the challenges found in training and competition. Furthermore, there is a lack of conceptual clarity surrounding the definition of mental toughness, and the multidimensionality of mental toughness (Clough et al., 2002; Crust, 2008, 2008a; Gucciardi et al., 2014).

We can speculate, that there may be a number of facets to Mental Toughness not identified within this study: a trait that we are born with, an element that is context dependant, and even factors which are shaped by the adoption of coping mechanisms, goal setting or attentional focus. Attentional focus and motivation may therefore deserve further consideration in relation to performance success in endurance events. Baden, Warwick-Evans, and Lakomy (2004) suggest that fatigue is indeed subjective and can be influenced by expectations regarding task duration. Such teleoanticipatory mechanisms may be influenced by coping strategies or attentional focus and may be modified as a result of endurance-focused training. Baden et al. (2004) reported that a lower rate of perceived exertion (RPE) is a result of dissociative thoughts diverting attention from physical cues, whilst Brick et al. (2014) suggest that researchers may wish to investigate whether or not cognitive strategies, including association, dissociation, self-talk and goal setting, negate the impact of factors known to affect perceived exertion and endurance performance. Mental fatigue appears to affect perceived exertion, and this may be a result of its impact on the central processing of sensory inputs (Marcora et al, 2010). This leads to speculation that appropriate mental training may reduce mental fatigue and thereby limit the rate of perceived exertion (Mccormick et al., 2015).

According to the work of Montgomery et al. (1998), participants with the ACE gene insertion allele are more likely to achieve greater endurance benefits from exercise training. Surprisingly, though it had been hypothesised that, as per Montgomery et al. (1998, 2011), the ultra-marathon group would have a higher incidence of the insertion allele of the ACE gene, compared with the non-ultra-marathon group, there was no significant difference in the ACE gene allele between the ultra-marathon group and the non-ultra-marathon group. An implication of this is the possibility that *both* the D allele, linked with strength, and the I allele, linked with endurance (Montgomery et al., 1998), are equally important and complimentary. As many of the ultra-marathoners race in mountain environments that include considerable ascent and descent both strength and endurance would provide benefit and value in training, and participation in such events. Furthermore, a single gene test may not provide a sufficient indication of the genetic predisposition of an individual to succeed in ultra-endurance events. Indeed, as a result of advances in research methods, many studies into exercise response phenotypes have rejected the candidate gene approach, and instead favoured a hypothesis-free, genome-wide method of investigation (Gronde et al., 2013; Lippi et al., 2009; Puthucheary et al., 2011). Due to cost and time limitations, this study was limited to an analysis of a single gene, and therefore future hypothesis-free, genome-wide investigations is warranted to identify the genetic predisposition of an individual to succeed in ultra-endurance events. Though worthy of future study, the ACE gene is likely to be one of many possible genes that impact human endurance. At present, both approaches are providing valuable insight into the molecular basis of $\dot{V}O_{2max}$ trainability, and research has indicated a degree of heritability approaching 47% (Sarzynski et al., 2017).

The results of correlational analysis show that for all participants there is a positive relationship between $\dot{V}O_{2peak}$ and conscientiousness. It is not possible, based on analysis of results from, and methodological limitations of, Study 1, to identify the direction of association between aerobic capacity, as measured by maximal oxygen uptake, and conscientiousness. Indeed, it may be speculated that mental toughness is heightened as a result of a prolonged programme of endurance training and subsequently provides the individual with a number of factors that improve the likelihood of success in an ultra-marathon. For the ultra-marathoners, conscientiousness may be a prerequisite for determination and focus in training, to reach higher levels of aerobic fitness, and during racing, to achieve maximal results. Conscientiousness may provide an incentive to achieve optimal results in, what is for some a possibly unfamiliar, aerobic environment during treadmill testing for both ultra-marathoners and non-ultra-marathoners. Indeed, previous research has hypothesised that conscientious may be predictive of endurance success due to its association with the ability to persist (Allen et al., 2011; Malinauskas et al., 2014). Training in psychological based techniques including goal setting, coping, and visualization may therefore provide useful mechanisms for ultra-marathoners, and non-ultra-marathoners, to more easily achieve their potential. There were also strong, positive correlations between $\dot{V}O_{2peak}$, and commitment and overall mental toughness for all participants. Analysis therefore suggests, independent of whether or not an individual competes in ultra-marathon events, that specific personality traits, and attributes of mental toughness may influence aerobic fitness, or conversely that aerobic fitness impacts on the non-heritable element of psychological traits, and they are indeed not fixed.

There are other explanations for the lack of significant differences between the two groups in terms of psychological measures, and the single ACE gene allele: it could be that traits other than those selected for inclusion within Study 1 could be examined; or, that the two populations are homogeneous in terms of their measured traits. If the latter is true, then perhaps, as Bramble and Lieberman (2004) suggest, we are, as a species, designed for endurance, with highly developed, specialised features that may have provided a significant contribution to the evolution of the human form. Evolutionary psychology has had some success in explaining psychological traits as important evolutionary outcomes (Buss, 2009; 2009a; Penke & Jokela, 2016), with adaptations designed to solve the problems faced by our ancestors and may provide some insight into the shared pre-prerequisites for endurance activities.

This study set out to establish whether the psychological and physiological factors as measured influence performance in ultra-marathoners and non-ultra-marathoners. From the findings, it can be suggested that for mental toughness, personality and the ACE gene allele, the two groups are homogeneous, with the increased $\dot{V}O_{2peak}$ in the ultra-marathoners likely to be a result of the increased volume of training. An implication of this study, with consideration given to the limitations cited, is that, based on the traits tested, any non-ultra-marathoner, with suitable training and an absence of health problems, could become a competitor in ultra-marathons. This study has limited ecological validity and therefore does not identify what it takes to become a more highly ranked ultra-marathoner in a race. By measuring physiological and psychological traits, when compared with race success, it may be possible to more comprehensively understand the attributes that provide a competitive advantage, and how improved race times, or more consistent results, can be achieved. Study 3 (Chapter 6), by inclusion of race placings as an additional measure, will therefore differentiate between ultra-running participants able to complete the event and those that are able to achieve a good placing.

A further, and important, limitation of this study is the heterogeneity of the non-ultra-marathoner group, including both sedentary individuals, and well trained runners that have not participated in an ultra-marathon - potentially even marathon runners. Study 2 (Chapter 5) will further delineate the non-ultra-marathon group to account for this limitation. Motivation is likely to be a necessary precursor to the adoption, and the ongoing continuance, of training to participate in ultra-running, endurance events defined by higher levels of aerobic endurance. Such motivation may be present in all of us, as an inherited predisposition to participate, and even enjoy, endurance activities, necessary to ensure the survival of our human ancestors. If this is an inherited trait, then it is likely to be identified in all of us: something in our development, situation or environment may be limiting its expression for the majority who do not currently, and do not intend to, train for and participate in, such activities. Motivation has not been explored previously with a protocol similar to Study 1, therefore Study 2 and 3 will include measurements to help better understand whether motivation is a predicting factor in ultra-marathon performance.

Although the findings should be treated with caution, for the limitations discussed, the results of this study indicate, that psychological factors, including personality and mental toughness, impacted by inheritability, are not factors in participation in ultra-marathons, and as they are in contrast to an existing body of research (Allen et al., 2011; Crust & Clough, 2005; Kaiseler et al., 2017; Montgomery et al., 2011) further investigation with a strengthened methodological protocol to Study 1 is warranted.

CHAPTER FIVE

5. Study 2: Identification of the Psychological and Physiological Factors that Enable Endurance Performance Success in Trained Ultra-marathoners.

Abstract

Psychological and physiological factors were examined, as part of a cross-sectional, interdisciplinary study, to ascertain what influenced performance in ultra-marathon runners who were aerobically trained compared with low aerobic participants. The 27 participants were all male (M age = 39.41, SD = 6.95): 10 had previously taken part in an ultra-marathon; 10 participants had not competed in an ultra-marathon and averaged a minimum of 30 minutes of moderate exercise on most, if not all days of the week; and 7 took part in physical activity for less than 90 minutes over the course of a week. Participants completed the Mental Toughness Questionnaire MTQ48, SDT GCOS Questionnaire, and the Big 5 Personality Inventory, along with physiological assessment of $\dot{V}O_{2peak}$ scores, pain tolerance and threshold, stress hormone, lactate threshold, running economy, and the 5HTT, BDNF, D4DR gene expression profile. There was a significant difference between the ultra-marathoner group and the low aerobic group on $\dot{V}O_{2peak}$, running velocity at lactate inflection point, and rate of increase of RPE, and the Big 5 dimension, openness. There were no differences between ultra-marathoners, the aerobic, and the low aerobic groups on mental toughness, motivation scores, and pain tolerance and threshold. There were significant positive correlations, for all participants, between aspects of mental toughness and, pain tolerance and threshold ($p < .05$), and running economy ($p <.05$). Together these findings suggest that ultra-marathoners are identifiable by their openness to new experiences but not their mental toughness, or motivation and achieved higher levels of endurance as a result of physiological adaptions following increased training regimes.

5.1. Introduction

The association between psychological and physiological parameters, with endurance performance, is widely accepted and has been confirmed by a number of investigations to date (McCormick et al., 2015; Schüler et al., 2014). Mental toughness, in particular, is recognised as an important psychological concept in sporting success and, as a result, has received considerable attention within research into enhancing performance in sport (Gucciardi, 2017; Perry et al., 2013; Thelwell et al., 2010; 2008). However, despite work having identified mental toughness as facilitating improved determination, focus, and the ability to manage pressure in sport, there has been limited focus with those who run ultra-marathons. Indeed, analysis of data from recent research by Marshal et al. (2017) suggested that mental toughness increased as a result of training for a long-distance triathlon, and a study by Mahoney et al. (2014), of cross-country runners, reported that increased mental toughness is related to reduced race times.

Motivation has also been linked to health and sporting behaviour (Hagger & Chatzisarantis, 2008; Ryan & Deci, 2017), and according to Deci and Ryan (2008) tends to be high when the basic psychological needs, competence, autonomy, and relatedness, are met (Deci & Ryan, 2008). The Self-determination Theory (SDT) (Deci & Ryan, 1985) provides a framework to study human motivation, and the General Causality Orientation Scale (GCOS) measures enduring motivational orientation, by testing 36 items, that describe typical, social and achievement-oriented situations, with responses indicating either an autonomous, controlled, or impersonal type of motivation (Deci & Ryan, 1985).

Ultra-endurance events are long, and gruelling, and as with all aerobic activities involve a number of complex, interrelated, physiological processes, resulting in, but not limited to, the production of stress hormones, including cortisol, and an increase in lactate. Cortisol secretion increases with exercise intensity, and helps counter hypoglycaemia, accelerates fat mobilisation, and results in post-exercise levels usually being significantly higher than pre-exercise (Tanner et al., 2013; Wortley & Islas, 2011). Salivary testing has been identified as a convenient means of collecting and quantifying cortisol levels and is indicative of the amount of stress athletes have put their body though during training, racing, and testing (Inder, Dimeskit, Russell & Warrick, 2012; Tanner et al., 2013). Blood lactate, produced as a result of glucose utilisation, serves as an important substrate in the generation and storage of energy, during both rest, when lactate production is usually in balance with removal, and increasingly during anaerobic exercise, when lactic clearance is insufficient to prevent its accumulation (Brooks et al., 2005; McArdle, Katch & Katch, 2015).

Despite the tendency for long distance runners to maintain a pace well below anaerobic threshold, participants frequently experience discomfort, and even pain, over the course of an ultra-marathon (Simpson et al., 2014). Research into pain in sport may provide a greater understanding of the challenges experienced by athletes and identify those strategies that benefit tolerance and management. Evidence from psychophysiological studies examining sports injury, have reported that mentally tough athletes are more likely to accept pain and perceive it as less threatening (Levy, Polman, Clough, Marchant & Earle, 2006) and may, in part, help explain the ability of ultra-marathoners to appear to push beyond previous boundaries during races.

Athletes at all levels of training and competition have performance limits, however Marcora and Staiano (2010) have challenged the popular view that the length of aerobic exercise is constrained by muscle fatigue. Their research shows that the perception of effort, rather than the inability of fatigued muscles to deliver the necessary power output, is the limiting factor impacting endurance performance and predicting failure (Crewe et al., 2008; Eston, 2012; Marcora et al., 2009; Pageaux et al., 2014). The Rate of Perceived Exertion (RPE) is commonly utilised to provide subjective feedback of exercise intensity and integrates both psychological, and physiological factors, to predict pacing strategy and the duration of exercise. Research suggests the RPE is moderated by psychological factors, including cognition, memory, previous experience, understanding of the task, and situational factors such as knowledge of the end point, duration, temporal characteristics of the event or training session (Eston, 2012; Noakes, 2007).

In Study 1 (Chapter 4), ultra-marathoners, and non-ultra-marathoners, completed psychological tests for mental toughness, using the MTQ48 (Crust et al., 2005), and the Big 5 Personality Inventory, alongside the physiological assessment of aerobic capacity ($\dot{V}O_{2peak}$). The failure to identify differences between groups for the psychological factors may result from the study limitations, previously discussed, including the heterogeneity of the non-ultra-marathoners (see Section 4.4). By enhancing the methodological research design and protocol in Study 1, Study 2 further delineated the non-ultra-marathon group, into an aerobically trained group, and a low aerobically trained group.

The Mental Toughness Questionnaire (MTQ48) (see Section 3.1) and the Self-determination Theory (SDT), as measured by the GCOS scale, have been utilised extensively to study a wide variety of sport-related behaviours, yet there have been few applications of such theoretical frameworks in ultra-marathoners (Crust & Clough, 2005; Deci & Ryan, 1985). In this second laboratory-based cross-sectional study, the aim was to further investigate factors that influence performance in 'trained' ultra-marathoners, quantifying: (a) mental toughness; (b) personality traits; (c) motivation that may impact performance; (d) cortisol; (e) pain threshold and tolerance; (f) genes 5HTT, BDNF and D4DR, identified as potentially affecting emotional control, perceived effort, and motivation; and (g) $\dot{V}O_{2peak}$, and lactate thresholds, as measures of maximal aerobic capacity. Further research into the above psychological and physiological factors may provide an improved understanding of the challenges experienced by athletes in endurance events and enable scientists to provide more informed support to the athlete whilst seeking performance improvements.

Three hypotheses were tested: a) it is hypothesised there will be no significant differences between the mental toughness, personality, and motivation scores from questionnaires completed by ultra-marathon runners, aerobic and those in the low aerobic group; b) there will be no significant differences in the measurements of the $\dot{V}O_{2peak}$, lactate inflection point, stress hormone cortisol and training volume; and finally c), there will be no significant differences in the expression of the genes 5HTT, BDNF, D4DR between ultra-marathon runners, non-ultra-marathon runners and those in the low aerobic group.

5.2. Methods

5.2.1. Participant Characteristics

In response to the sample size estimation from the power calculation in Section 3.2.1, twenty-seven adult male volunteers, aged between 25-60 years (mean age 39.41 $\pm$ SD 6.95), were recruited by word of mouth, or social media to take part. Participants were asked to complete a health and training questionnaire and based on aerobic exercise and ultra-marathon race participation, were consequently allocated to one of three groups. Those participants who had (a) previously completed an ultra-marathon event within the last 8 months, (b) were training for an event in the next 3 months, and (c) currently averaging more than four hours of cardiovascular exercise per week, were allocated to the *ultra-marathon* group. Whilst those that averaged a minimum of 30 minutes of moderate exercise on most, if not all days, of the week, and had not taken part, and were not planning to take part, in an ultra-marathon were allocated to the *aerobic* group. And finally, those participants that took part in physical activity for less than 90 minutes, and had not taken part, and were not planning to take part, in an ultra-marathon, were allocated to the *minimal aerobic group.*

The ultra-marathon group trained on average between 270 minutes and 720 minutes per week (mean number of minutes trained 468.0 $\pm$ SD 136.53), though largely attributed to running, this did include cycling and swimming. The aerobic group trained on average aerobically between 150 minutes and 450 minutes per week (mean number of minutes trained 291.0 $\pm$ SD 93.86). The low aerobic group trained on average aerobically between 0 minutes and 90 minutes per week (mean number of minutes trained per week 47.14 $\pm$ SD 29.28).

5.2.2. Experimental Design

Ulster University Research Ethics Committee (UREC) approval was granted (REC.16.0041). Human tissue was sampled, tested and stored in accordance with the Human Tissue Act (HTA) 2004.

5.2.3. Psychological Measures

Mental Toughness

Mental toughness was measured using the Mental Toughness Questionnaire (MTQ48) (Clough et al., 2002). A detailed description can be obtained by referring to Methodology Section 3.3.1.

Personality

Personality was measured using the Big 5 Personality Inventory (Kaiseler et al., 2012). A detailed description can be obtained by referring to Methodology Section 3.3.2.

Motivation

Motivation was measured using the Self-determination Theory, General Causality Orientation Scale (GCOS) (Deci & Ryan, 1985). A detailed description can be obtained by referring to Methodology Section 3.3.3.

5.2.4. Physiological Measures

Maximum Oxygen Uptake ($\dot{V}O_{2max}$ Test)

Maximum oxygen uptake was measured using an incremental exercise on a motorised treadmill, increasing the running speed after each one-minute interval. A detailed description can be obtained by referring to Methodology Section 3.4.1.

Rating of Perceived Exertion (RPE)

RPE was recorded every minute through the maximum oxygen uptake test, based on the Borg 6-20 scale (Borg, 1982; Heath, 1998). A detailed description can be obtained by referring to Methodology Section 3.4.2.

Running Economy

Running Economy was recorded as the submaximal oxygen ($\dot{V}O_2$) at a running velocity of 15km/hr (Barnes & Kilding, 2014) and was achieved by all participants. A detailed description can be obtained by referring to Methodology Section 3.4.3.

Pain Threshold and Tolerance

Pain threshold and tolerance was measured using an ice bath (Samuel & Ebenezer, 2013). A detailed description can be obtained by referring to Methodology Section 3.4.4.

Lactate Inflection Point

Lactate inflection point was measured using a portable lactate analyser, at 3-minute intervals on a treadmill. A detailed description can be obtained by referring to Methodology Section 3.4.5.

Stress Hormones

Cortisol changes were determined, as a biomarker for physiological stress, following analysis of saliva levels prior to, and following, the protocol for quantifying maximum oxygen uptake. A detailed description can be obtained by referring to Methodology Section 3.4.6.

Genetic Testing for the Polymorphism of the 5HTT, BDNF and D4DR Genes

Semi Quantitative PCR was performed to compare the expression patterns of the 5HTT, BDNF and D4DR genes. A detailed description can be obtained by referring to Methodology Section 3.5.2.

5.2.5. Data Analysis

A total of 10 participants were tested in the ultra-marathon group, 10 participants were tested in the aerobic group, and 7 participants volunteered for testing in the low aerobic group. Descriptive statistics were calculated for the 27 male participants.

Table 5.1 - *General Descriptive Statistics*

Measurement	Grouping	Mean	SD	N
Height (cm)	Ultra	179.89	9.23	10
	Aerobic	178.66	3.38	10
	Low	173.91	4.80	7
	Total	177.89	6.69	27
Weight (kg)	Ultra	73.42	6.54	10
	Aerobic	79.39	8.49	10
	Low	86.74	15.47	7
	Total	79.08	11.10	27
Average Aerobic exercise per week (minutes)	Ultra	468.00	136.53	10
	Aerobic	291.00	93.86	10
	Low	47.14	29.28	7
	Total	293.33	194.30	27

5.2.6. Learning and Development

Existing general areas of learning and development, completed for Study 1 were further enhanced for the successful completion of Study 2, and included: (1) recruitment of participants, including communication, sharing and completion of health and training questionnaires using SurveyMonkey; (2) ethics committee submission and revision; (3) design and following of research protocol; (4) collection and organisation of data; (5) usage of health and training questionnaires created for Study 1; (6) taking and storage of bloods and saliva according to Human Tissue Act.

Existing specific areas of learning and development, completed for Study 1 were further enhanced for the successful completion of Study 2, and included: (1) maximal oxygen uptake testing; (2) SPSS data analysis. Additional specific areas of learning and development, building on Study 1 included: (3) taking and recording Lactate Threshold; (4) protocol and measurement of pain threshold and tolerance; (5) analysis of RNA in a wet lab; (6) analysis of cortisol from cortisol in lab (7); recording of Rating of Perceived Exertion; (8) analysis and calculation of SDT GCOS scores.

5.3. Results

5.3.1. Physiological Measures

Table 5.2 - *Physiological Characteristics of Participants*

Measurement	Grouping	Mean	SD	N
$\dot{V}O_{2peak}$ (ml/min^{-1}/kg^{-1})	Ultra	59.09	6.14	10
	Aerobic	58.00	6.42	10
	Low	50.31	6.99	7
Running economy i.e. $\dot{V}O_2$ at 15km/hr (ml/min^{-1}/kg^{-1})	Ultra	49.59	7.06	10
	Aerobic	51.68	3.33	10
	Low	50.01	3.32	7
Heart Rate when Lactate inflection point was reached (Beats per minute)	Ultra	164.54	12.43	10
	Aerobic	171.23	11.13	10
	Low	164.90	20.51	7
Running velocity when Lactate inflection point was reached (km/hr)	Ultra	14.82	1.42	10
	Aerobic	14.30	2.06	10
	Low	10.98	1.36	7
Rate of increase of Rating of Perceived Exertion (RPE)	Ultra	1.39	0.27	10
	Aerobic	1.48	0.18	10
	Low	2.02	0.57	7

There was a difference between $\dot{V}O_{2peak}$ scores from the low aerobic group (M = 50.31, SD = 6.99) to the ultra-marathon group (M = 59.09, SD = 6.14), a mean increase of 8.78, 95% CI [.83, 16.74], which was statistically significant ($p < .05$).

There was higher running velocity when lactate inflection point was reached from the low aerobic group (M =10.98, SD =1.36) to the ultra-marathon group (M = 14.82, SD = 1.42), a mean increase of 3.84, 95% CI [1.78, 5.9], which was statistically significant ($p < .001$).

There was a decrease in rate of increase of RPE, from the low aerobic group (M = 2.02, SD = .57) to the ultra-marathon group (M = 1.39, SD = .27), a mean increase of -.62, 95% CI [-1.05, -.19], which was statistically significant ($p = .004$). Rate of increase of RPE was defined as the slope, or angle, of the line of best fit.

Pain Measures

There were no statistically significant differences for pain tolerance and pain threshold between ultra-marathon, aerobic and low aerobic groups on the combined dependent variables, $F(4, 46) = .174$, $p > .05$; Wilks' $\Lambda = .97$; $\eta_p^2 = .01$

Biochemical Indices

There were no statistically significant differences for cortisol pre-testing, cortisol post-testing and the change in cortisol between ultra-marathon, aerobic and low aerobic groups on the combined dependent variables, $F(4, 44) = .89$, $p > .05$; Wilks' $\Lambda = .95$; $\eta_p^2 = .02$

RNA Expression

There were no statistically significant differences for BDNF, D4DR and 5HTT RNA expression between ultra-marathon, aerobic and low aerobic groups on the combined dependent variables, $F(6, 20) = 1.08$, $p > .05$; Wilks' $\Lambda = .57$; $\eta_p^2 = .24$

5.3.2. Psychological Measures

Mental Toughness

There were no statistically significant differences between ultra-marathon, aerobic and low aerobic groups on the combined MTQ48 variables dependent variables, $F(18, 32) = 1.35$, $p > .05$; Wilks' $\Lambda = .32$; $\eta_p^2 = .43$, see Table 5.3.

Table 5.3 - *Partial-eta for each of the Individual ANOVA's Performed*

Psychological Measure	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared (η_p^2)
MTQ48 Challenge	0.416	2	0.21	0.83	0.45	0.06
MTQ48 Commitment	0.730	2	0.36	1.15	0.33	0.09
MTQ48 Control Total	0.282	2	0.14	0.47	0.63	0.04
MTQ48 Control - emotion	0.050	2	0.02	0.08	0.93	0.01
MTQ48 Control - Life	1.235	2	0.62	1.46	0.25	0.11
MTQ48 Confidence Total	0.241	2	0.12	0.47	0.63	0.04
MTQ48 Confidence - Abilities	0.310	2	0.15	0.64	0.54	0.05
Confidence - Interpersonal	0.936	2	0.47	0.97	0.39	0.07
MTQ48 Total	0.306	2	0.15	0.72	0.50	0.06

Self-determination Theory

There were no statistically significant differences for SDT scores for autonomy, control and impersonal, between ultra-marathon, aerobic and low aerobic groups on the combined dependent variables, SDT variables, $F(6, 44) = .97$, $p > .05$; Wilks' $\Lambda = .78$; $\eta_p^2 = .12$.

Big 5 Personality Inventory

There was a statistically significant difference in Big 5 Openness scores (see Table 5.4) between the participants in each group, $F(2, 24) = 3.93$, $p < .05$; $\eta_p^2 = .247$. The effect size is large according to the partial eta-squared value.

There was an increase in Openness from the low aerobic group ($M = 2.91$ $SD = .51$) to the ultra-marathon group ($M = 3.59$ $SD = .54$), a mean increase of -.67, 95% CI [.05, 1.3], which was statistically significant ($p < .05$).

Table 5.4
Partial-eta Squared for each of the Individual ANOVA's Performed

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared (η_p^2)
Extraversion	0.82	2	0.41	0.62	0.54	0.05
Agreeableness	0.49	2	0.24	0.65	0.53	0.05
Conscientiousness	0.43	2	0.22	0.77	0.47	0.06
Neuroticism	0.10	2	0.50	0.89	0.42	0.07
Openness	2.00	2	1.00	3.93	0.03	0.24

Rating of Perceived Exertion (RPE)

There was a decrease in Rate of increase of RPE, from the low aerobic group (M = 2.02 SD = .57) to the ultra-marathon group (M = 1.39 SD = .27), a mean increase of -.62, 95% CI [-1.05, -.193], which was statistically significant (p = .004).

5.3.3. Correlational Analysis

Correlations Between Psychological and Physiological Factors

Table 5.5 shows the results of the correlational analyses performed between psychological and physiological factors.

There were significant correlations between: (a) running economy and MT - control life $r(25) = -.409$, $p < .05$; (b) pain threshold and MT challenge $r(25) = .40$, $p < .05$; (c) pain tolerance and MT confidence interpersonal $r(25) = .47$, $p < .05$; (d) amount of weekly aerobic exercise and, $\dot{V}O_{2peak}$ $r(25) = .57$, $p < .01$, running velocity at lactate inflection point $r(25) = .68$, $p < .01$; (e) cortisol pre-test, and agreeableness $r(25) = -.55$, $p < .01$

Table 5.5 - *Correlations between Physiological and Psychological factors*

Physiological Factor	Correlation	N	Pearson Correlation	Significance 2-tailed
Running Economy	Mental Toughness – Control Life	27	-.41*	0.03
Pain Threshold	Mental Toughness – Challenge	27	.40*	0.04
Pain Tolerance	Mental Toughness – Confidence Interpersonal	27	.47**	0.01
Average aerobic exercise per week (minutes)	Number of ultras	27	.06**	0.00
	Weight	27	-.39*	0.05
	$\dot{V}O_{2peak}$	27	.57**	0.00
	Running velocity at Lactate inflection point (km/hr)	27	.68**	0.00
Cortisol – Pre test	Weight	26	-.40**	0.04
	Agreeableness	26	-.55**	0.00
	Lactate HR	26	-.48**	0.01

Where significance 2-tailed = 0 this represents p < .005
* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

There were significant positive correlations between Self-determination Theory (SDT) GCOS, and Big 5 – Agreeableness and Openness, and MTQ48 Challenge, Commitment and Confidence – Abilities scores shown in Table 5.6

Table 5.6
Correlations between Motivational Measures (SDT) and other Psychological Factors

Physiological Factor	Correlation	N	Pearson Correlation	Significance 2-tailed
SDT – Autonomy	MTQ48 Challenge	27	.51**	0.01
	MTQ48 Commitment	27	.38*	0.05
SDT – Impersonal	Big 5 Extraversion	27	-.73**	0.00
	Big 5 Conscientiousness	27	-.40*	0.04
	Big 5 Neuroticism	27	.53**	0.00
	MTQ48 Challenge	27	-.48**	0.01
	MTQ48 Commitment	27	-.43*	0.02
	MTQ48 Control - Total	27	-.58**	0.00
	MTQ48 Control - Emotion	27	-.43*	0.02
	MTQ48 Control - Life	27	-.58**	0.00
	MTQ48 Confidence Total	27	-.74**	0.00
	MTQ48 Confidence - Abilities	27	-.65**	0.00
	MTQ48 Confidence – Interpersonal	27	-.65**	0.00
SDT – Control	Big 5 Agreeableness	27	-.40*	0.04
	MTQ48 Commitment	27	-.41*	0.03
	MTQ48 Control – Total	27	-.42*	0.03

Where significance 2-tailed = 0 this represents p < .005

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

There were significant positive correlations between Big 5 personality and both SDT and MTQ48 shown in Table 5.7

Table 5.7 - *Correlations between Big 5 Personality Measures and other Psychological Factors*

Physiological Factor	Correlated with	N	Pearson Correlation	Significance Two--tailed
Big 5 – Extraversion	SDT Impersonal	27	-.73**	0.00
	MTQ48 Control Total	27	.60**	0.00
	MTQ48 Control – Emotion	27	.45*	0.02
	MTQ48 Control Life	27	.58**	0.00
	MTQ48 Confidence – Total	27	.70**	0.00
	MTQ48 Confidence – Abilities	27	.68**	0.00
	MTQ48 Confidence – Interpersonal	27	.53**	0.00
Big 5 – Agreeableness	SDT Impersonal	27	-.40*	0.04
	MTQ48 Control - Emotion	27	.39*	0.05
Big 5 – Conscientiousness	MTQ48 Challenge	27	.46*	0.01
	MTQ48 Commitment	27	.81**	0.00
	MTQ48 Control Total	27	.48*	0.01
	MTQ48 Control Life	27	.54**	0.00
	MTQ48 Confidence – Total	27	.42*	0.03
	MTQ48 Confidence – Abilities	27	.43*	0.03
	SDT Impersonal	27	-.40*	0.04
Big 5 – Neuroticism	SDT Impersonal	27	.53**	0.00
	MTQ48 Challenge	27	-.41*	0.03
	MTQ48 Commitment	27	-.44*	0.02
	MTQ48 Control – Total	27	-.83**	0.00
	MTQ48 Control – Emotion	27	-.70**	0.00
	MTQ48 Control – Life	27	-.75**	0.00
	MTQ48 Confidence – Total	27	-.83**	0.00
	MTQ48 Confidence – Abilities	27	-.73**	0.00
	MTQ48 Confidence – Interpersonal	27	-.71**	0.00
Big 5 – Openness	MTQ48 Challenge	27	.46*	0.01
	MTQ48 Confidence – Abilities	27	.42*	0.03

Where significance 2-tailed = 0 this represents $p < .005$

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

There were significant positive correlations within MTQ48 Mental Toughness, SDT and Big 5 shown in Table 5.8

Table 5.8
Correlations between Mental Toughness Measures and other Psychological Factors

Physiological Factor	Correlated with	N	Pearson Correlation	Significance Two--tailed
MTQ48 – Challenge	SDT – Autonomy	27	.51**	0.00
	SDT – Impersonal	27	-.48*	0.01
	Big 5 – Conscientiousness	27	.46*	0.01
	Big 5 – Neuroticism	27	-.41*	0.03
	Big 5 - Openness	27	.46*	0.01
	Pain Threshold	27	.40*	0.04
MTQ48 – Commitment	SDT – Autonomy	27	.38*	0.05
	SDT – Control	27	-.41*	0.03
	SDT – Impersonal	27	-.43*	0.02
	Big 5 – Conscientiousness	27	.81**	0.00
	Big 5 – Neuroticism	27	-.44*	0.02
MTQ48 – Control Total	SDT – Control	27	-.42*	0.03
	SDT – Impersonal	27	-.58**	0.00
	Big 5 – Extraversion	27	.60**	0.00
	Big 5 – Conscientiousness	27	.48*	0.01
	Big 5 – Neuroticism	27	-.83**	0.00
MTQ48 – Control Emotion	SDT – Impersonal	27	-.43*	0.02
	Big 5 – Extraversion	27	.45*	0.02
	Big 5 – Agreeableness	27	.39*	0.05
	Big 5 – Neuroticism	27	-.70**	0.00
MTQ48 – Control Life	SDT – Impersonal	27	-.58**	0.00
	Big 5 – Extraversion	27	.58**	0.00
	Big 5 – Conscientiousness	27	.54**	0.00
	Big 5 – Neuroticism	27	-.75**	0.00
	Running Economy	27	-.41*	0.03
MTQ48 – Confidence Total	SDT – Impersonal	27	-.74**	0.00
	Big 5 – Extraversion	27	.70**	0.00
	Big 5 – Conscientiousness	27	.42*	0.03
	Big 5 – Neuroticism	27	-.83**	0.00
MTQ48 – Confidence Ability	SDT – Impersonal	27	-.65**	0.00
	Big 5 – Extraversion	27	.68**	0.00
	Big 5 – Conscientiousness	27	.43*	0.03
	Big 5 – Neuroticism	27	-.73**	0.00
	Big 5 – Openness	27	.42*	0.03
MTQ48 – Confidence Interpersonal	Pain Tolerance	27	.47*	0.01
	SDT – Impersonal	27	-.65**	0.00
	Big 5 – Extraversion	27	.53**	0.00
	Big 5 – Neuroticism	27	-.71**	0.00

Where significance 2-tailed = 0 this represents $p < .005$

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

5.4. Discussion

Study 2 was designed to identify the psychological and physiological differences between ultra-marathoners and non-ultra-marathoners participating in either regular aerobic exercise or completing a minimal volume of regular aerobic exercise. The present study ascertained that ultra-marathoners are identifiable by their openness to new experiences but not their mental toughness, or motivation. In support of the findings of Study 1 (Chapter 4), this study reported that a higher volume of aerobic training appears to be associated with improved fitness, as evidenced by $\dot{V}O_{2peak}$, running velocity at lactate inflection point, and RPE, for both the ultra-marathon group, and the aerobic group, when compared with the group performing minimal aerobic exercise. This study identified a moderate relationship between increased mental toughness and running economy, pain threshold and tolerance. This suggests that although mental toughness does not predict participation in ultra-marathons, it may benefit factors that impact performance in ultra-marathon events.

This discussion will firstly consider the associated psychological measures, including mental toughness, personality and motivation, of participants, and the lack of significant differences between ultra-marathoners and non-ultra-marathoners, except openness. The second part of the discussion will consider the physiological differences including aerobic capacity, running velocity at lactate inflection point, and rate of increase in RPE. An examination of 5HTT, BDNF, D4DR gene expression across groups will be outlined, along with a discussion of the potential impact of the study findings on our understanding of how heritability impacts endurance performance, both in test and under race conditions. The discussion will further consider limitations of the study, and future research, throughout.

An implication of this study, is that ultra-marathoners are not higher in mental toughness, as measured by the MTQ48 instrument, than non-ultra-marathoners. Findings are in contrast to the majority of research into mental toughness in sport, that suggest mental toughness is associated with sporting performance and success (Connaughton et al., 2008; Crust & Clough, 2005; Gucciardi et al., 2016; Jones et al., 2002). In contrast, to the vast majority of research, which has focussed on elite athletes, a more recent study, including recreationally active participants, also failed to identify any significant differences between levels of triathlon training and mental toughness (Marshall et al., 2017). Lack of differences in mental toughness may be a result of methodological limitations resulting from the validity, and accuracy, of measuring mental toughness via the self-report nature of the MTQ48. Furthermore, if mental toughness is indeed a state-like psychological resource, which though enduring, may vary across situations or time (Gucciardi, 2017, 2017a), and measures are recorded at different point in training or in completion, scoring may be affected. It is therefore questionable whether the participants measured can be mentally tough all the time, leading to the suggestion that mental toughness whilst some properties may persist, there may be study limitations in its measurement (Gucciardi, 2017). Researchers have also raised a concern that the MTQ48 may be less appropriate to specific populations that require language more apposite to the context (Gucciardi et al., 2016), in this research, ultra-marathoners. There are therefore limitations within this study, including the assumption that performance success can be measured via tests in a lab, raising concerns regarding ecological validity, and therefore challenge the associations identified between mental toughness and physiological. Additionally, fundamental concerns have been raised regarding the arbitrariness of measures, validity, and usefulness, of the concept of mental toughness itself, and the possibility that the conceptual underpinning of the MTQ48 are unsubstantiated or that the metrics used are arbitrary (Blanton & Jaccard, 2006; Gucciardi et al., 2012).

Limited research exists regarding either the ability of mentally tough athletes to manage pain, or the quantitative, or qualitative, measurement of pain in ultra-marathoners. Research by Levy et al. (2006) interviewed seventy patients undertaking a sports injury clinic for tendonitis and ascertained that mentally tough athletes were more likely to accept pain and perceive it as less threatening. However, pain measurements taken from athletes competing in extreme, multi-day, foot race suggested, higher cold pain tolerances than controls (Freund et al., 2013), and research into knee pain suggested that mental toughness impacted behaviour in response to pain (Gucciardi et al., 2016). The current study however has failed to associate pain threshold or tolerance with participation in ultra-marathons. However, inconsistencies may be due to the nature of the pain, or discomfort experienced, and methodological limitations, due to a focus on quantitative scoring. Measurement of pain through cold water immersion may differ qualitatively from the discomfort, or pain, experienced during an endurance event, and this may suggest the need for additional research to more comprehensively understand the nature of suffering, within context, during an ultra-marathon. Indeed, research by O'Leary, Collett, Howells & Morris (2017) muscle pain tolerance can be increase in response to multiple exposure to high-intensity training and warrants further research.

Analysis of data from Study 2 suggests that ultra-marathoners are identifiable through openness, and therefore are open to new challenges, but are not identifiable according to the remaining Big 5 personality traits, comprised of conscientiousness, extraversion, agreeableness and neuroticism. This is in contrast to findings of other, larger studies exploring personality, although the vast majority of sports researchers focus on elite athletes, with a paucity of research in to amateur sports (Allen et al., 2011; Kaiseler et al., 2012, 2017). Though personality has been linked with sports performance, results have been contradictory, with limited knowledge regarding the effect personality has on appraisal, coping effectiveness in sport, and the ability to handle stress (Kaiseler et al., 2017). Furthermore, evidence from population-based studies appears to be difficult to generalise and associations between personality and success in sport have been unconvincing (Allen et al., 2011). In previous research into exercise capacity, no differences were identified in openness, extraversion, agreeableness and neuroticism when athletes scored against non-athletes, but higher scores were observed for conscientiousness (Malinauskas et al., 2014). Allen et al. (2011) observed a relationship between the Big 5 personality traits and the selection of coping strategies, prediction of short-term behaviours and long-term success, and differences between higher and lower level athletes. Effect sizes in this study indicate that if the population were larger there may be a statistical significance between the ultra-marathon group, and the non-ultra-marathon group.

Although used to study a wide variety of sport-related behaviours, there have been few investigations into the application of motivational frameworks in ultra-marathoners. The review performed by Roebuck (2018) identified only 9 studies, with a consensus that ultra-marathoners took part in the sport: (1) to achieve personal goals, (2) for reasons related to health, (3) for reasons of self-esteem. Analysis of the data from the current study shows that motivation, as defined by the self-determination theory, is not a factor in training for, or the completion of, an ultra-marathon. The General Causality Orientation Scale (Deci & Ryan, 1985) was utilised to measure enduring motivational orientation, by testing items, that describe typical, social or achievement-oriented situations with responses indicating either an autonomous, controlled, or impersonal type of motivation. Based on a review of the literature, no other research has utilised the SDT GCOS instrument to measure motivation in ultra-marathoners. This study is limited to measurement of the participants orientations, using the SDT GCOS scale, and other instruments may have been more apposite. Indeed, a previous study, attempting to better understand the motivation to run, using an alternative set of instruments, did report increased intrinsic motivation in ultra-marathoners compared with half-marathoners and marathoners (Hanson et al., 2015). In addition, Krouse et al. (2011) identified ultra-marathoners as being more internally motivated, and Ferrer et al. (2015) found health-related motivation were positively linked to the amount of distance covered in a time-limited ultra-marathon.

Participation in ultra-endurance races places participants under varying levels of both psychological and physiological stress (Lac & Berthon, 2000). Acute physical stress has been shown to increase levels of the hormone cortisol, and testosterone, in the body, with post-exercise levels typically observed to be significantly higher than pre-exercise levels when participants took part in interval, tempo and circuit training (Tanner et al., 2013). Results of previous studies indicate levels of cortisol tend to increase as a product of both the intensity and duration of exercise, whilst testosterone tends to fall, following an initial increase, after 3 or more hours of exercise (Lac & Berthon, 2000). In contrast, the lack of positive correlations between mental toughness and changes in the stress marker cortisol, measured prior to, and following, maximal aerobic testing, suggests either, there is no increased ability by mentally tough participants to push their physiology to a greater intensity, or, that other psychological factors are involved in overall race success not included in Study 2.

The findings of this study suggest that participants, with increased levels of agreeableness, have lower levels of pre-test stress. This may be as a result of a tendency to be more cooperative, and less suspicious, resulting in lower levels of agitation, or according to other research, athletes exposed previously to physiological stress from exercise may become accustomed and exhibit reduced levels of stress hormones (Tanner et al., 2013). Also, other research suggests cortisol levels may be suppressed at later stages of an ultra-marathon event, potentially avoiding subsequent negative impacts of continually high cortisol levels (Deneen & Jones, 2017). A reduction in pre-test stress may benefit participants in terms of reduced interruption to mental preparation, though this was not evidenced by improved aerobic measures in this study. However, it is believed that pre-competition, increased cortisol levels may be an adaptive response, and can help athletes to meet the demands of competition (Kivlighan et al., 2005). In addition, this study did not consider, or control for, other conflicting factors, including time of day, or duration or intensity of training immediately prior to testing, that may affect results (Lac & Berthon, 2000; Tanner et al., 2013).

$\dot{V}O_{2max}$ measures the maximum rate at which oxygen is consumed during oxidative phosphorylation, the metabolic pathway supplying energy used to reform adenosine triphosphate (ATP), and is highly correlated with maximal cardiac output. Despite the frequent use of maximal oxygen consumption ($\dot{V}O_{2max}$) to assess overall physical fitness and provide a measure of the body's ability to deliver oxygen to working muscles, questions have been raised regarding its efficacy as a good predictor of performance in endurance events (Haff & Dumke 2012; Tsigilis, 2005). Analysis of results from the present programme of research indicate that the maximum ability of the oxidative system to produce ATP during exercise, which is the highest rate at which oxygen can be taken up, and transported to skeletal muscles and utilised for running, is higher in ultra-marathoners than in those who perform little training (Haff & Dumke 2012). Although a difference between groups was not evident for motivation, it is worth noting that the termination of the $\dot{V}O_{2peak}$ test may be driven by motivational factors, rather than physiological parameters (McArdle et al., 2015). Prior research has identified a strong association between intrinsic motivation and performance of a shuttle test, a commonly used technique, to measure aerobic fitness and predict $\dot{V}O_{2max}$ (Tsigilis, 2005). In addition, and a further limitation of this study, for participants with less experience of aerobic training, reaching a plateau in oxygen consumption requires a high level of anaerobic energy output and dealing with the accompanying discomfort may prove difficult.

The strong association between hours of training per week, and $\dot{V}O_{2peak}$ scores, across all participants, explains why the ultra-marathoner group have the highest aerobic capacity. However, this may not equate directly to ultra-marathon performance, other factors may persist, including the considerable contribution from the human genome (Bouchard et al., 1995; Timmons, 2011), along with the ability of the runner to maintain the highest percentage of the maximum $\dot{V}O_{2peak}$ scores throughout the endurance event. Indeed, analysis of research data, has suggested a strong association between the maximum sustainable speed that can be maintained during an ultra-marathon, the maximum oxygen uptake, and the fraction of it that can be maintained, and the energy cost of running in marathon and half marathon distance races (Gimenez et al., 2013).

Study 2 failed to identify significant differences between the participant groups and the expression patterns of the 5HTT, BDNF and D4DR genes, believed to affect the psychological background impacting training and competition. An implication of the data analysis is that the serotonin transporter gene (5HTT), which appears to be linked with the ability to control emotion, the brain-derived neurotrophic factor (BDNF), which appears to be directly impact perceived effort during aerobic activity, and the dopamine receptor gene (D4DR), which appears to affect the dopaminergic system, involved in both motivation, arousal and risk-taking behaviour, do not predict participation in, or affect success during, ultra-marathons (Carpenter et al., 2011; Eichhammer et al., 2005; Lippi et al., 2009). Though ultra-marathoners have been exercising on a regular basis in advance of the testing it may not have led to an elevated gene expression profile for these genes. The lack of significant difference in the dopamine receptor gene (D4DR) expression, is in contrast to the findings that identify clear differences in the personality trait, openness, despite links to risk-taking behaviour. On the basis of these results it can be suggested that D4DR is not linked to openness. It should however be noted as a methodological limitation, that bloods were not take before, and after, aerobic testing; therefore, this study did not identify long term upregulation or downregulation, rather than transient, changes to the genetic expression of the 5HTT, BDNF and D4DR genes, as seen in existing research (Ulucan, 2016).

A further limitation arises from the participants included in the study. The findings cannot be extrapolated beyond those tested; neither females nor elite athletes were included as participants and warrants future research. In addition, this study's aim was to measure and compare psychophysiological factors between ultra-marathoners and non-ultra-marathoners, the research design did not facilitate analysis of the intra-relationships between factors in individual ultra-marathoners.

Key strengths of this study include the further delineation of non-ultra-marathoners tested in Study 1, and the clear examination of participants from a variety of physical abilities, including well-trained ultra-marathoners, aerobically fit non-ultra-marathoners, and minimally trained, low aerobic participants. The analysis compares physiological measures against psychological factors including motivation, mental toughness and personality. Analysis of the findings does not provide support for the view that mental toughness is a key factor in endurance success, or that mentally tough ultra-endurance runners are more likely to reach increased levels of physiological stress. As discussed, limitations of this study include the recognition that all testing was performed under laboratory conditions, which may lack ecological validity and not be representative of success in the context of an endurance challenge, and that psychological and physiological measurement was at a single time point, which is not likely to be consistent across training schedules for all runners. Although the findings should be treated with caution, for the limitations discussed, the results of this study indicate that psychological factors, including personality and mental toughness, impacted by inheritability, are not factors in participation in ultra-marathons in the current sample and as they are in contrast to an existing body of research, warrant further investigation. Further research, detailed in Study 3 (Chapter 6), was required to more comprehensively understand the motivations of runners, the personality and mental toughness measures, outside of the laboratory, when compared with levels of success within an ultra-marathon race setting.

CHAPTER SIX

6. Study 3: Psychological and Physiological Factors Influencing Ultra-Marathon Race Performance: A Field Experiment

Abstract

Psychological and physiological factors were examined, as part of a repeated measures, interdisciplinary study, to ascertain what influenced successful performance in ultra-marathoners, as measured by race placings, within a single event. Participants were all male (M age = 41.82, SD = 10.02) participating in a 60km off road ultra-marathon. Participants completed psychological tests for mental toughness (Mental Toughness Questionnaire 48), motivation (Self-determination Theory, SDT GCOS Scale) and personality dimensions (Big 5 Personality Inventory), along with the physiological measurement of stress hormone changes, including testosterone and cortisol, as biomarkers of physiological stress, and important indicators of the effort expended. There were no differences between cortisol measures recorded in advance of, and following the event, however there was a significant decrease in testosterone. There were significant negative correlations, between pre-event cortisol and, confidence (MTQ48) ($p < .05$) and extraversion ($p < .05$), and positive correlations between pre-event cortisol and neuroticism ($p < .05$). There were significant negative correlations, between post-event cortisol and, impersonal motivation (SDT) ($p < .05$), between age and absolute race position ($p < .05$), and between age and all mental toughness factors ($p < .05$). Collectively, these findings suggest that mental toughness, personality and motivational measurements did not predict race success, but that some psychological characteristics impact the stress hormone, cortisol. Additionally, the study demonstrated a significant relationship between age of the participant and associated race times, wherein there was a decline in race performance with increased age.

6.1. Introduction

Completion of an ultra-marathon requires overcoming both psychological and physiological challenges, with multiple factors influencing performance, including competition taking place in difficult environments: extreme weather conditions, terrain, and considerable changes in elevation (Baumann et al., 2014; Knechtle et al., 2010; Krouse et al., 2011; Zach et al., 2017). There is a growing body of research quantifying the physiological and psychological factors that predict performance success in sport, but little is known about the impact of these factors outside of a laboratory setting and how they can predict race times in ultra-marathon events (Holt et al., 2014; Pearson, 2006). At the cost of losing experimental control, conducting research at an ultra-endurance event has its advantages, as it can increase ecological validity and provide opportunities for generalisability to race performance.

Indeed, Holt et al. (2014) examined athletes' experiences of running an ultra-marathon by performing qualitative data collection techniques throughout the duration of an event, and identified that runners use coping strategies, and psychological skills, including monitoring pace, nutrition and hydration, and breaking down the demands of the race into achievable goals. In another study, involving self-reported measures of trait emotional intelligence, during a multi-day ultra-marathon, analysis of results suggested that runners accept fatigue as necessary to achieve goals (Lane & Wilson, 2011). Few interdisciplinary studies have attempted to compare psychological measures with either race success, or physiological stress, as measured by the changes in the hormone, cortisol.

Researchers have shown that personality characteristics can, in part, predict whether an athlete participates at a certain level of competition, and can also impact the selection of coping mechanisms that may affect sporting performance (Allen et al., 2011). Analysis into the benefits of individual traits in sport, has demonstrated that conscientious athletes are more likely to use emotion-focussed strategies, and thereby change their personal reactions to the stressor, whilst extraverted athletes, open to new experiences and emotionally stable, are more likely to adopt problem-focussed strategies, concentrating on resolving the problem in an attempt to reduce the stressors (Allen et al., 2011). Conscientiousness has been reported as being significantly higher in athletes than non-athletes, underpinned by both common genetic and non-shared environmental factors, and linked to mental toughness (Horsburgh et al., 2009; Malinauskas et al., 2014).

Mental toughness has been described as a complex psychological concept linked to the ability to consistently optimise human performance despite contextual demands (Crust & Keegan, 2010; Mahoney et al., 2014; 2014a). Early research by Crust and Clough (2005) into mental toughness identified a strong link with physical endurance during a dumbbell holding task and suggested that mentally tough participants benefit from a buffering effect that blocks out pain. More recently, research by Cowden (2016) identified significant relationships between mental toughness and performance indicators within tennis competitions; whilst in a subsequent review (Cowden, 2017), three studies, out of ten that examined competitive standard differences in mental toughness, used the MTQ48. A study of adolescent cross-country runners reported that mental toughness was inversely associated with race times (Mahoney et al., 2014). Based on their findings, Mahoney et al. (2014) suggested that mental toughness may be linked to variables within the Self-determination Theory of motivation (see Section 3.3.3 for a description), and that a more comprehensive understanding of both mental toughness and SDT may facilitate researchers in understanding behaviour that will then translate into improved support for optimal human functioning in sport.

In environments where basic psychological needs, of autonomy, relatedness competence, are met individuals experience a greater sense of well-being as they move closer to states characterised as autonomous or self-volitional (Section 2.2.2). Despite SDT (Deci & Ryan, 2008) providing a useful model to measure the basic needs fulfilment of relatedness, autonomy and competence, researchers to date have not identified a direct link with endurance race success. However, indirectly, there is a large volume of published peer reviewed studies describing the role of autonomy, relatedness and competence in supporting well-being and a reduction in stress and of potential benefit to endurance sport (Weinstein & Ryan, 2011).

A stressor can be defined as a situation identified by the individual as exceeding their resources and consequently the ability to manage and reduce stress is likely to be of benefit in sport, including participation in ultra-marathon races in which participants are placed under high degrees of both psychological and physiological stress (Holt et al., 2014; Lac & Berthon, 2000). As a result, the effect of psychological factors may provide an insight into those that offer protection, and coping mechanisms, and warrants further study. Acute physiological stress has been shown to increase endogenous hormones such as cortisol and testosterone, with post-exercise concentrations significantly higher than pre-exercise (Tanner et al., 2013). Cortisol changes were determined, as a biomarker for physiological stress, important indicators of the effort expended.

Collectively these studies provide an insight into the physiological and psychological factors that influence successful performance in sport but fall short of providing a model to predict race success in endurance events. Indeed, despite research findings suggesting that training intensity, improved running economy, and sufficient recovery time are positively linked with race performance, a study of cardiorespiratory parameters in multi-stage mountain marathon racers, measured in a laboratory environment, failed to predict race success (Barnes & Kilding, 2014; Gatterer et al., 2013; Knechtle et al., 2010). Gatterer et al., (2013) suggested that ultra-marathoners need a moderate, but not an extraordinary $\dot{V}O_{2max}$, and that pain tolerance, mental toughness, and pacing strategy should be explored further.

Despite considerable research in the field of mental toughness and personality in sport, relatively little attention has been directed towards quantitative research to identify whether mental toughness, personality and motivation anticipate success in an ultra-marathon race. The main aim of this study was to test the use of MTQ48, Big-5 Personality Inventory, and the Self-determination Theory GCOS for predicting success, as measured by time to finish, and placing, in an ultra-marathon race. A secondary aim was to contribute to current understanding of endurance athletes competing in an ultra-marathon event by exploring relationships between mental toughness, personality, motivation, race times, and changes in stress hormone biochemistry. This is the first study to quantify psychological factors in ultra-marathoners participating in a single race and will contribute to knowledge by identifying those measures that predict successful performance. Three hypotheses will be tested: a) it was hypothesised that there will be no significant positive correlation between race success, as represented by a lowered finishing race position and time, and mental toughness, personality scores and motivational scores from questionnaires completed by ultra-marathon runners; b) it was hypothesised that there will be no significant correlation between changes in the stress hormone measurements taken from the ultra-marathon racers, and mental toughness, personality scores and motivational scores from questionnaires completed by ultra-marathon runners; and finally c) it was hypothesised there will be no significant differences in the measurements of the stress hormones, cortisol and testosterone, between ultra-marathon participants prior to, and following, competition.

6.2. Methods

6.2.1. Participant Characteristics

With agreement from the race organiser (26 Extreme, Northern Ireland, http://www.26extreme.com), an email was sent to 70 male race entrants registered for the 2015 Causeway Coast ultra-marathon in Northern Ireland to invite them to be involved in the study. The ultra-marathon is an annual running race covering 40 miles of rugged, undulating coastline, mostly off-road, on paths, tracks, beaches and cliff tops. 21 adult males got in contact and were subsequently recruited via email, one subsequently decided not to proceed with the study as a participant, leaving a total of 20 adult male participants (mean age 41.82 $\pm$ SD 10.02) who were asked to complete an online health questionnaire and training questionnaire (see Section 9.1) using SurveyMonkey. If no pre-existing physical conditions prevented participation, they were included in the study. All participants were fully briefed regarding the testing protocol prior to measurement.

6.2.2. Experimental Design

Ulster University Research Ethics Committee (UREC) granted approval for this study (REC.15.0050). Human tissue was sampled, tested and stored in accordance with the Human Tissue Act (HTA) 2004.

A repeated measures design was adopted. Psychological parameters were recorded in advance of a chosen ultra-marathon race whilst cortisol and testosterone concentration were sampled at 2 time-points, immediately prior to, and following, successful competition.

6.2.3. Psychological Measures

Mental Toughness

Mental toughness was measured using the Mental Toughness Questionnaire (MTQ48) (Clough et al., 2002). A detailed description can be obtained by referring to Methodology Section 3.3.1.

Personality

Personality was measured using the Big 5 Personality Inventory (Kaiseler et al., 2012). A detailed description can be obtained by referring to Methodology Section 3.3.2.

Motivation

Motivation was measured using the General Causality Orientation Scale (GCOS) (Deci & Ryan, 1985). A detailed description can be obtained by referring to Methodology Section 3.3.3.

6.2.4. Physiological Measures

Stress Hormones

Cortisol changes were determined, as a biomarker for physiological stress, and an indicator of effort, following analysis of saliva levels prior to, and following, competition. A detailed description can be obtained by referring to Methodology Section 3.4.6.

6.2.5. Data Analysis

During analysis of the results, three participants were excluded: one participant failed to complete the psychological questionnaires and provide saliva samples, and two participants did not finish (DNF) the ultra-marathon event. One of the post-race cortisol values was identified as a univariate outlier, as assessed by inspection of a boxplot, and subsequently removed from further statistical analysis. Saliva from 11 of the 17 participants was provided for cortisol and testosterone analysis immediately prior to competition, and 9 participants provided samples immediately after competition. Only 7, of the 17, participants had both pre and post data saliva samples for direct comparison. Descriptive statistics were calculated based on the results from all the remaining 17 volunteers (M age = 41.82, SD = 10.02).

6.2.6. Descriptive Statistics

Mean and standard deviation scores, including participant final race position, age, and psychological measures are presented in Table 6.1.

6.2.7. Learning and Development

Existing general areas of learning and development, completed for Study 1 and 2, were further enhanced for the successful completion of Study 3 and included: (1) recruitment of participants, including communication, sharing and completion of health and training questionnaires using SurveyMonkey; (2) ethics committee submission and revision; (3) design and following of research protocol; (4) collection and organisation of data; (5) usage of health and training questionnaires created for Study 1.

Specific areas of learning and development used in Study 1 and 2, and enhanced for Study 3, and included: (1) SPSS data analysis; (2) analysis and calculation of Big 5, MTQ48, SDT

GCOS scores; (3) analysis of cortisol from cortisol in lab (4). Additional specific areas of learning and development, building on Study 1 and 2 included: (5) taking and storage of saliva according to Human Tissue Act in a race environment.

Table 6.1
Age, Training, Psychological and Physiological Characteristics

Measures	Mean	SD	N*
Age	41.82	10.02	17
Hours Training (highest in last four weeks)	9.01	2.63	17
Race Position (Absolute)	32	23.55	17
Time to complete race (seconds)	27307.94	4688.39	17
Race Position (Relative)	9.00	5.05	17
Pre-race Cortisol (µg/dL)	.37	0.15	11
Post-race Cortisol (µg/dL)	.89	0.73	9
Difference between two measurements of cortisol (µg/dL)	.26	0.36	7
Pre-race Testosterone (pg/mL)	115.27	38.56	11
Post-race Testosterone(pg/mL)	97.26	30.71	9
Difference between two measurements of testosterone (pg/mL)	-35.20	34.08	7
SDT - Autonomy	5.69	0.65	17
SDT - Control	3.7	0.63	17
SDT - Impersonal	3.02	0.99	17
Big 5 - Extraversion	3.23	0.86	17
Big 5 - Agreeableness	3.90	0.65	17
Big 5 - Conscientiousness	3.89	0.67	17
Big 5 - Neuroticism	2.55	0.88	17
Big 5 - Openness	3.53	0.58	17
MTQ48 - MT Total	3.68	0.51	17
MTQ48 – MT Challenge	3.94	0.61	17
MTQ48 – MT Commitment	3.93	0.54	17
MTQ48 – MT Control Total	3.57	0.54	17
MTQ48 – MT Control Emotion	3.34	0.67	17
MTQ48 – MT Control Life	3.79	0.60	17
MTQ48 – MT Confidence Total	3.48	0.62	17
MTQ48 – MT Confidence Ability	3.46	0.72	17
MTQ48 – MT Confidence Interpersonal	3.51	0.67	17

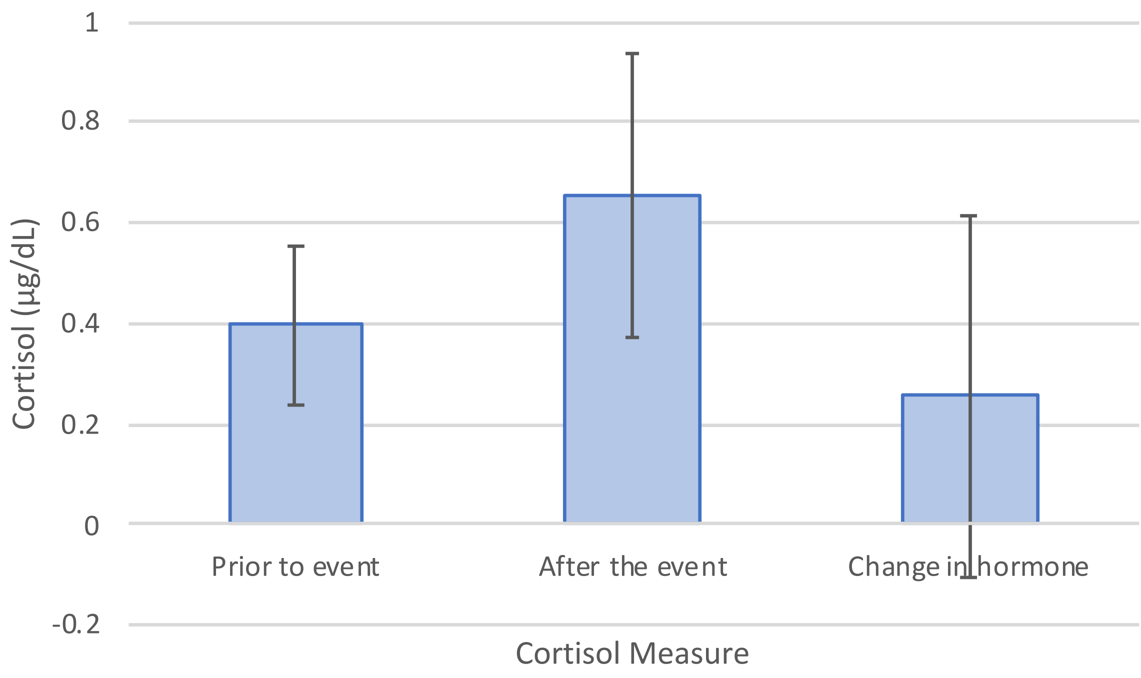
*Explanation of participant number
Total of 17 participants remaining following the exclusion of 3 participants.
11 participants gave a pre-race saliva sample
9 participants have a post-race saliva sample
7 participants had both a pre-race and a post-race saliva sample

6.3. Results

6.3.1. Analysis of Stress Hormones Changes During Competition

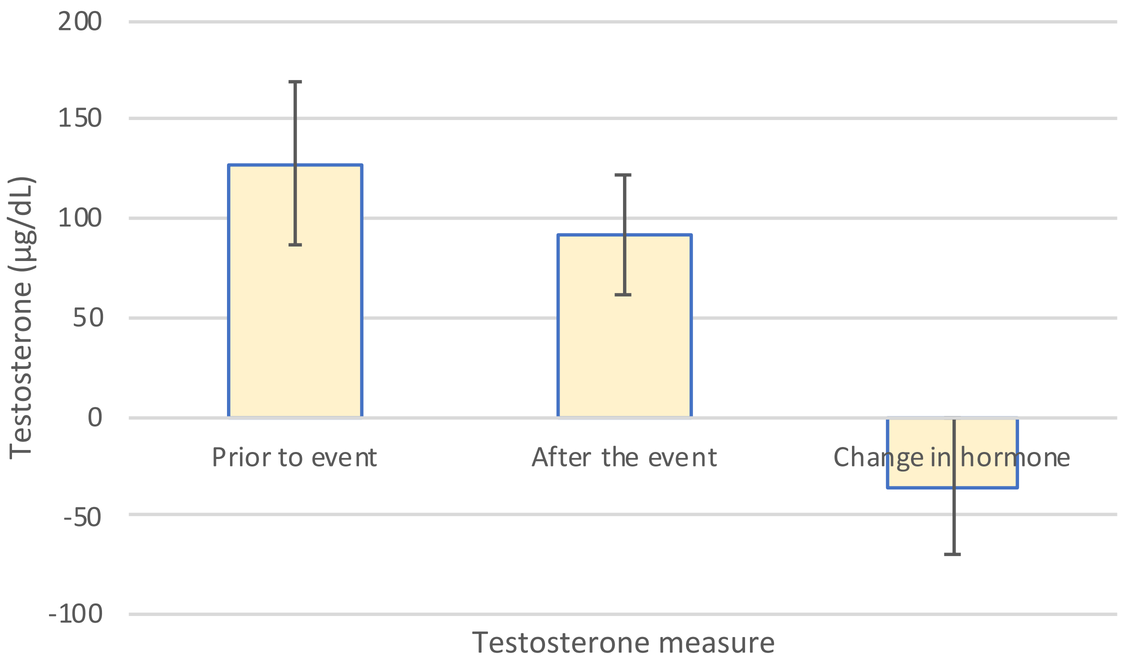
The ultra-marathon race did not elicit a significant change in cortisol between measures taken prior to ($M = .40$, $SD = .16$ $N = 7$) and following ($M = .65$, $SD = .28$, $N = 7$) competition $t(6) = -5.20$, $p = .109$. (See Figure 6.1). However, as N = 7, this is below the minimum participant number calculated in Section 3.2.1, and as a result underpowered.

Figure 6.1
Mean and Standard Deviation Scores for Cortisol prior to, and following, Competition, for Matched Samples



However, the ultra-marathon race elicited a significant decrease in testosterone between measures taken prior to (M = 127.41, SD= 41.35 N = 7) and following (M = 92.21, SD= 30.29, N = 7) completion $t(6) = 2.73$, $p < .05$. (Figure 6.2). However, as N = 7, this is below the minimum participant number calculated in Section 3.2.1, and as a result underpowered.

Figure 6.2
Mean and Standard Deviation Scores for Testosterone Prior to, and Following, Competition, for Matched Samples



6.3.2. Correlational Analysis

Analysis of Stress Hormones

Table 6.3 shows the results of the correlational analyses performed on stress hormones. There were no significant correlations between testosterone variables and psychological variables, or race success ($p > .05$).

The only statistically significant correlations ($p < .05$) between psychological measures and cortisol are shown in Table 6.3. Analysis of the results indicated large negative correlations between: (a) pre-race cortisol and, MT - total confidence $r(9) = -.66$, $p < .05$, MT - confidence abilities $r(9) = -.67$, $p < .05$, and extraversion $r(15) = -.66$, $p < .05$; (b) post-competition cortisol and SDT impersonal $r(7) = -.70$, $p < .05$; and (c) change in cortisol and SDT impersonal $r(5) = -.81$, $p < .05$.

There was a further, moderate to large, significant positive correlation between pre-race cortisol and neuroticism $r(9) = .65$, $p < .05$.

Table 6.3
Correlations between Hormonal Measures and Psychological Factors

Physiological Factor	Correlation	N	Pearson Correlation (r)	Significance 2-tailed
Pre Race Cortisol	Mental Toughness – Confidence Total	11	-.66*	.03
	Mental Toughness – Confidence Abilities	11	-.67*	.02
	Neuroticism	11	.65*	.03
	Extraversion	11	-.66*	.03
Post Race Cortisol	SDT Impersonal	9	-.70*	.04
Change in Cortisol	SDT Impersonal	7	-.81*	.03

* Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level

Analysis of Training

There was a moderate positive correlation in all participants between number of hours training and MTQ48 Confidence - Interpersonal $r(15) = .57$, $p < .05$.

Analysis of Race Success

Race success, as represented by finishing race position, did not correlate with any psychological or physiological other variables, including mental toughness, personality, motivational or hormonal variable ($p > .05$), other than age ($p < .01$).

Table 6.4
Correlations between Age and Training, Psychological Measures and Performance

Physiological Factor	Correlation	N	Pearson Correlation (r)	Significance 2-tailed
Age	Absolute race position	17	.67**	.00
	Race time (seconds)	17	.73**	.00
	Neuroticism	17	.64**	.00
	Mental Toughness – Total	17	-.62**	.01
	Mental Toughness – Challenge	17	-.55*	.02
	Mental Toughness – Commitment	17	-.51*	.04
	Mental Toughness – Control Total	17	-.54*	.02
	Mental Toughness – Control Life	17	-.57*	.02
	Mental Toughness – Confidence Total	17	-.56*	.02
	Mental Toughness – Confidence Abilities	17	-.53	.02
Hours Training	Mental Toughness – Confidence Interpersonal	17	.57*	.016

* Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level

Analysis of Psychological Variables

All psychological variables were correlated, and the results show in Table 6.5, 6.6 and 6.7 a number of relationships identified.

Table 6.5
Correlations between Motivational Measures (SDT) and other Psychological Factors

Physiological Factor	Correlated with	N	Pearson Correlation	Significance 2-tailed
SDT – Autonomy	Big 5 Agreeableness	17	0.61**	0.01
	Big 5 Openness	17	0.56*	0.02
	MTQ48 Challenge	17	0.51*	0.04
	MTQ48 Commitment	17	0.49*	0.05
	MTQ48 Confidence – Interpersonal	17	0.55*	0.02
SDT – Impersonal	SDT – Autonomy	17	-0.55*	0.02
	Big 5 Extraversion	17	-0.62*	0.01
	Big 5 Neuroticism	17	0.56*	0.02
	MTQ48 Total	17	-0.76**	0.00
	MTQ48 Challenge	17	-0.71**	0.00
	MTQ48 Commitment	17	-0.71**	0.00
	MTQ48 Control - Total	17	-0.50*	0.04
	MTQ48 Control – Life	17	-0.67**	0.00
	MTQ48 Confidence – Total	17	-0.76**	0.00
	MTQ48 Confidence – Abilities	17	-0.65**	0.00
	MTQ48 Confidence – Interpersonal	17	-0.72**	0.00

Where significance 2-tailed = 0 this represents $p < .005$
* Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level

Table 6.6
Correlations between Big 5 Personality, MTQ48 and SDT

Physiological Factor	Correlation	N	Pearson Correlation	Significance Two-tailed
Big 5 – Extraversion	SDT Impersonal	17	-.62**	0.01
	MTQ48 Total	17	0.52*	0.03
	MTQ48 Challenge	17	0.53*	0.03
	MTQ48 Control Life	17	0.49*	0.04
	MTQ48 Confidence – Total	17	0.65*	0.00
	MTQ48 Confidence – Abilities	17	0.60*	0.01
	MTQ48 Confidence – Interpersonal	17	0.55*	0.02
Big 5 – Agreeableness	SDT – Autonomy	17	0.61**	0.01
	Big 5 Openness	17	0.71**	0.00
	MTQ48 Total	17	0.60*	0.03
	MTQ48 Challenge	17	0.57*	0.02
	MTQ48 Control – Life	17	0.70**	0.00
	MTQ48 Confidence – Total	17	0.52*	0.03
	MTQ48 Confidence – Abilities	17	0.56*	0.02
Big 5 – Conscientiousness	MTQ48 Challenge	17	0.51*	0.04
	MTQ48 Commitment	17	0.63**	0.01
Big 5 – Neuroticism	SDT Impersonal	17	0.56*	0.03
	MTQ48 Total	17	-0.85**	0.00
	MTQ48 Challenge	17	-0.74**	0.00
	MTQ48 Commitment	17	-0.52*	0.03
	MTQ48 Control – Total	17	-0.79**	0.00
	MTQ48 Control – Emotion	17	-0.69**	0.02
	MTQ48 Control – Life	17	-0.66**	0.00
	MTQ48 Confidence – Total	17	-0.87**	0.00
	MTQ48 Confidence – Abilities	17	-0.87**	0.00
	MTQ48 Confidence – Interpersonal	17	-0.62**	0.01
Big 5 – Openness	SDT - Autonomy	17	0.56*	0.02
	Big 5 – Agreeableness	17	0.71**	0.00
	Mental Toughness – Control Life	17	.554*	0.02

Where significance 2-tailed = 0 this represents $p < .005$
* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 6.7
Correlations between Mental Toughness Measures and other Psychological Factors

Physiological Factor	Correlated with	N	Pearson Correlation	Significance Two-tailed
MTQ48 – Total	SDT – Impersonal	17	-0.76**	0.00
	Big 5 – Extraversion	17	0.52*	0.03
	Big 5 – Agreeableness	17	0.52*	0.03
	Big 5 – Neuroticism	17	-0.85**	0.00
MTQ48 – Challenge	SDT – Autonomy	17	0.51*	0.04
	SDT – Impersonal	17	-0.71**	0.00
	Big 5 – Extraversion	17	0.53*	0.03
	Big 5 – Agreeableness	17	0.57*	0.01
	Big 5 – Conscientiousness	17	0.51*	0.04
	Big 5 – Neuroticism	17	-0.74**	0.00
MTQ48 – Commitment	SDT – Autonomy	17	0.49*	0.05
	SDT – Impersonal	17	-0.71**	0.00
	Big 5 – Conscientiousness	17	0.63**	0.01
	Big 5 – Neuroticism	17	-0.52*	0.03
MTQ48 – Control – Total	SDT – Impersonal	17	-0.50*	0.04
	SDT – Neuroticism	17	-0.79**	0.00
MTQ48 – Control – Emotional	SDT – Neuroticism	17	-0.69**	0.00

MTQ48 – Control Life	SDT – Impersonal	17	-0.67**	0.00
	Big 5 – Extraversion	17	0.49*	0.04
	Big 5 – Agreeableness	17	0.70**	0.00
	Big 5 – Neuroticism	17	-0.66**	0.00
	Big 5 – Openness	17	0.55*	0.02
MTQ48 – Confidence Total	Cortisol – Pre –race (means filled)	17	-0.57*	0.02
	SDT – Impersonal	17	-0.76**	0.00
	Big 5 – Extraversion	17	0.65**	0.00
	Big 5 – Agreeableness	17	0.52*	0.03
	Big 5 – Neuroticism	17	-0.87**	0.00
	SDT – Impersonal	17	-0.65**	0.00
	Big 5 – Extraversion	17	0.60*	0.01
	Big 5 – Agreeableness	17	0.56*	0.02
	Big 5 – Neuroticism	17	-0.87**	0.00
MTQ48 – Confidence Interpersonal	SDT – Autonomy	17	0.55*	0.02
	SDT – Impersonal	17	-0.72**	0.00
	Big 5 – Extraversion	17	0.55*	0.02
	Big 5 – Neuroticism	17	-0.62**	0.01

Where significance 2-tailed = 0 this represents $p < .005$
* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

6.4. Discussion

The aim of Study 3 was to test the effectiveness of the MTQ48, Big 5 personality model and the SDT GCOS for predicting successful race performance. From the findings, mental toughness, personality and motivational measurements did not predict race success, but that some psychological characteristics impact the stress hormone, cortisol. Additionally, the study demonstrated a significant relationship between age of the participant and associated race times, wherein there was a decline in race performance with increased age.

This discussion will firstly consider the psychological measures, including mental toughness, personality and motivation and the failure to predict race performance. The second part of the discussion will consider the differences in stress hormones prior to, and following, competition before considering the implications of both age and training on race performance. The discussion will further consider limitations of the study, and future research, throughout.

Based on the findings of Crust and Clough (2005) and Jones et al. (2002) it was anticipated that mentally tough ultra-marathoners would be more able to maximise their effort, and, as a potential consequence, improve race placing, and time, during competition (Mahoney et al., 2014). In addition, motivation, which according to SDT (Deci & Ryan, 2008), is based on an inherent tendency towards growth, has been identified as one of the key characteristics of mentally tough performers, and may function as a buffer, enabling the individual to observe setbacks as part of the process to success and optimise an athlete's performance (Jones et al., 2002; Weinstein & Ryan, 2011).

The most significant finding of this study is the lack of a relationship between psychological measures and ultra-marathon race success, and this can be explained by the proposition that either scoring highly in measures of mental toughness, motivation, or personality traits, does not identify top ultra-marathon performers, or a limitation of the study and the instruments utilised, the MTQ48 (Crust & Clough, 2005), SDT GCOS (Deci & Ryan, 1985), and Big 5 Factor Model, are not appropriate tools for ultra-marathon races. With regards the former, it is conceivable that optimum behaviours for ultra-marathon training and racing result from a balance of psychological attributes across the mental toughness, motivation and personality models utilised, producing the most appropriate behaviours, and resulting benefits. Extreme scores may lead to detrimental behaviour, whilst a more balanced outlook may be more likely to meet the needs of the ultra-marathoner, in not only commitments to the sport, but also in adjacent areas of life. For example, excessive commitment may lead to a loss of judgment in training and race decisions, and extreme confidence may result in unrealistic settings of goals, leading to disappointment and subsequent disengagement from the sport. There may be an optimum balance between mental toughness and mental sensitivity and diverse balances may be beneficial to each sport, or situation (Clough & Strycharczyk, 2012). A balance of personality traits, avoiding extremes, such as neurotic and extravert, may lead to an individual using a moderate approach to training and racing, potentially avoiding injury. A limitation of this study is that elite athletes were not included; such athletes, at the limits of preparedness may have offered additional insights into the extremes of personality. Further limitations raise a concern regarding the assumption that mental toughness, unlike personality, is context free. It seems plausible that the mental toughness of the mountaineer is different from the elite sprinter, or the ultra-marathoner (Crust, 2008, 2008a). If mental toughness varies by different sports, and cannot be generalised in all areas of life, this raises a question regarding the appropriateness of the MTQ48 as an instrument for testing mental toughness in endurance sports. Despite the ecological validity of the race environment, the timings of the measures of mental toughness, motivation and personality is a methodological limitation, as they were taken a number of days prior to the event and would not have identified fluctuations resulting from the proximity to the event that may have influenced results (Gucciardi, 2017; Gucciardi & Gordon, 2013). Furthermore, this study made assumptions that performance success is linked to race success, in contrast to the ability to overcome challenges both in training and during the event (Crust, 2008; Jones et al., 2002, 2007; Gucciardi et al., 2009; Thelwell et al., 2005). Finally, the information regarding training from participants provided detail of weekly duration, but not the terrain or intensity, it is therefore not possible to identify the level of race preparedness, or training, with race position.

In support of earlier research (Horsburgh et al., 2009), this study shows positive correlations between SDT's motivational subscale autonomy, measuring the extent someone takes ownership of their actions and initiates novel activities, and mental toughness, agreeableness and openness. The negative correlation between the motivational subscale impersonal, which measures a belief that a desired outcome is contingent on luck, or that it is outside the individual's control, and mental toughness, extraversion, and, as a potentially logical consequence, the increase in cortisol. According to Teixera, Carraca, Markland, Silva, and Ryan (2012) extrinsic motivation, which focuses on the outcome of exercise, may be a key factor in the adoption of exercise, whilst intrinsic motivation facilitates longer term participation in exercise. The impersonal subscale may be viewed as focusing on extrinsic conditions, and therefore be less important for endurance training, and racing, which requires prolonged commitment. A negative correlation with factors that influence the ability to push the limits of physiological stress would therefore seem a consequence.

Cortisol and testosterone are used widely as measures to assess the effects of differing types of exercise, and varying intensities, present in training and competition (Crewther et al., 2013). However, it has been recognised that limited research, particularly, outside of the laboratory, has focussed on the effects of ultra-marathons on the neuroendocrine system, one of many organ systems activated during an ultra-marathon (Deneen & Jones, 2017). It is difficult to perform a detailed meta-analysis, with studies varying in mode of exercise, duration and intensity, making generalisations difficult (Tanner et al., 2013). The lack of significant intra-individual change in cortisol, and the significant decrease in testosterone, recorded prior to and following competition, is in contrast to previous research, though it has been recognised that other factors impact results, including time of day, duration and intensity of recent training (Lac & Berthon, 2000; Tanner et al., 2013). In addition, the findings of this study show that confident, extraverted participants, with reduced neuroticism, have lower pre-race stress. Though it is understood that pre-competition, increased cortisol levels may be an adaptive response, and can help athletes to meet the demands of competition (Kivlighan et al., 2005), other research suggests that athletes exposed previously to a physiological stress from exercise, may become accustomed and exhibit reduced stress hormones (Tanner et al., 2013). A reduction in pre-race stress may benefit participants in terms of reduced interruption to mental preparation, though this was not evidenced by improved running times in this study. Surprisingly, the results of correlational analysis show that for all participants there is a positive relationship between being motivated and believing attainment of our goals is outside of our control, rather than taking responsibility for one's own behaviour, and the increase in the size of the change in cortisol over the course of the ultra-marathon. This increase in cortisol may be linked to the individual's preparation for action, which over the length of an endurance race, could be ongoing, and prolonged, and the size of the increase may indicate reduced resilience to a situation of potential stress (Kivlighan et al., 2005). However, failure to obtain saliva samples on all participants prior to, and after, the event impacted the results of statistical analysis, and resulted in a failure to reach the required sample size (see Section 3.2.1).

The study supports the findings of Knechtle at al. (2012), where they also report a decline in race performance, as measured by increased time to finish, and mental toughness, with age. Due to methodological limitations, and the study design, there are insufficient measures to predict whether the increase in race times was a result of an age-related decline in physiological or psychological mechanisms, but it does highlight that age, rather than mental toughness, motivation, or Big 5 Personality Dimensions, is a more significant factor in this experiment in predicting time to complete the race. Previous studies that have provided evidence for a decline in physiology, Knechtle at al. (2011) commented that reduced endurance performance is primarily a result of an age-related decline in $\dot{V}O_{2max}$ along with a change in muscle mass tissue. However, there are also likely to be psychological aspects, as per the observed reduction in mental toughness, and increase in neuroticism, which may have negatively impacted aerobic success, as per the findings of Study 1.

Collectively the findings show, that no single factor, other than age, directly affects the time taken to complete the race, and consequently the race finisher's position. Measures that influence race success may therefore be either absent from the study, or success is reliant on the interaction of multiple factors.

In addition, this study was limited to participants in a single ultra-marathon race of 64.37 km across a variety of terrains on the north coast of Northern Ireland; other distances, in other locations and climates, with alternate racers, may have yielded a different set of data. These data may not therefore be generalisable to ultra-marathon races of greater differences, including multi-day events, with a more varied, international field, or extremes in weather.

Study 3 has many strengths, including a clear examination of participants of a variety of physical abilities, in the context of a single race situation, and measures their success against psychological factors including motivation, mental toughness and personality. This study provides no support to the view that a high score in mental toughness is a predictor of endurance success. There may be an optimum set of scores, not necessarily all high, between mental toughness, personality and motivation that enables an athlete to train and race to their physical limits. The findings suggest that motivated ultra-marathoners are more likely to reach increased physiological stress and realise their physical potential during an endurance race. Further research, both in the field and in the laboratory, is required to more comprehensively understand the rewards, reasons and motivations behind successful race training and participation, and to better appreciate the interaction of multiple factors across the models of personality, mental toughness and motivation, along with identifying the techniques that subsequently support the athlete most appropriately.

CHAPTER SEVEN

7. General Discussion

7.1. Testing the Null Hypothesis (H_0)

The following section will consider the outcomes of the four hypotheses which were tested in Studies 1, 2 and 3.

Null hypothesis A - There will be no statistically significant differences between the psychological scores from questionnaires completed by ultra-marathon and non-ultra-marathon runners in Studies 1 and 2.

Null Hypothesis Rejected

Mental toughness and personality were not significantly different, in Study 1, between ultra-marathoners and non-ultra-marathoners. However, in Study 2, Openness (Big 5 personality dimension) was significantly different between the ultra-marathon group, and the low aerobic group. The findings from Study 2 provide the basis to accept the alternative hypothesis as there are significant differences in the measurements of openness (Big 5 personality dimension) quantified between ultra-marathon and non-ultra-marathon runners.

Null hypothesis B - There will be no statistically significant differences in the measurements of the physiological factors between ultra-marathon and non-ultra-marathon runners in Studies 1 and 2.

Null Hypothesis Rejected

$\dot{V}O_{2peak}$, and running velocity at lactate threshold, were significantly different between ultra-marathoners and non-ultra-marathoners in Studies 1 and 2, whilst running economy, pain threshold and pain tolerance were not. The findings provide the basis to accept the alternative hypothesis previously stated as there are significant differences in the measurements of the physiological factors quantified between ultra-marathon runners and non-ultra-marathon runners

Null hypothesis C - There will be no statistically significant association between the incidents of the alleles, or the genetic expressions, and the ultra-marathon and non-ultra-marathon runners in Studies 1 and 2.

Null Hypothesis Accepted

There were no associations with being in the ultra-marathon group and either having the ACE gene allele, or the expression of the genes 5HTT, BDNF, D4DR. The findings provide the basis to accept the null hypothesis previous stated as there are no significant differences in the incidents of the alleles, or the genetic expressions, tested between ultra-marathon runners and non-ultra-marathon runners.

Null hypothesis D - There will be no statistically significant correlation between race success, as represented by a lowered finishing race position and time, and mental toughness, personality scores and motivational scores from questionnaires completed by ultra-marathon runners in Study 3.

Null Hypothesis Accepted

Mental toughness, motivation and personality were not correlated with race success, as measured by time to complete or race position. The findings provide the basis to accept the null hypothesis previously stated as there is no significant correlation between race success, as represented by a lowered finishing race position and time, and mental toughness, personality scores and motivational scores from questionnaires completed by ultra-marathon runners.

7.2. General Discussion

The objectives of the general discussion are to integrate and summarise the research findings of all three studies, and examine the relationships between psychological and physiological factors, including measures of endurance performance, comprising of: mental toughness, motivation, personality, $\dot{V}O_{2peak}$ scores, pain tolerance and threshold, stress hormone, lactate threshold, running economy, rating of perceived exertion, and selected genes. The findings challenge existing psychological models of mental toughness, motivation and personality to successfully identify ultra-marathoners, and provide support for an interdisciplinary model of performance success in ultra-marathons, integrating measures from both psychology and physiology. Consequently, findings from all four studies will be interpreted to propose a new interdisciplinary Optimum Balanced Performance Model of Endurance success (OBPMES) in ultra-marathons. Finally, the discussion will highlight methodological limitations and outline recommendations for future research.

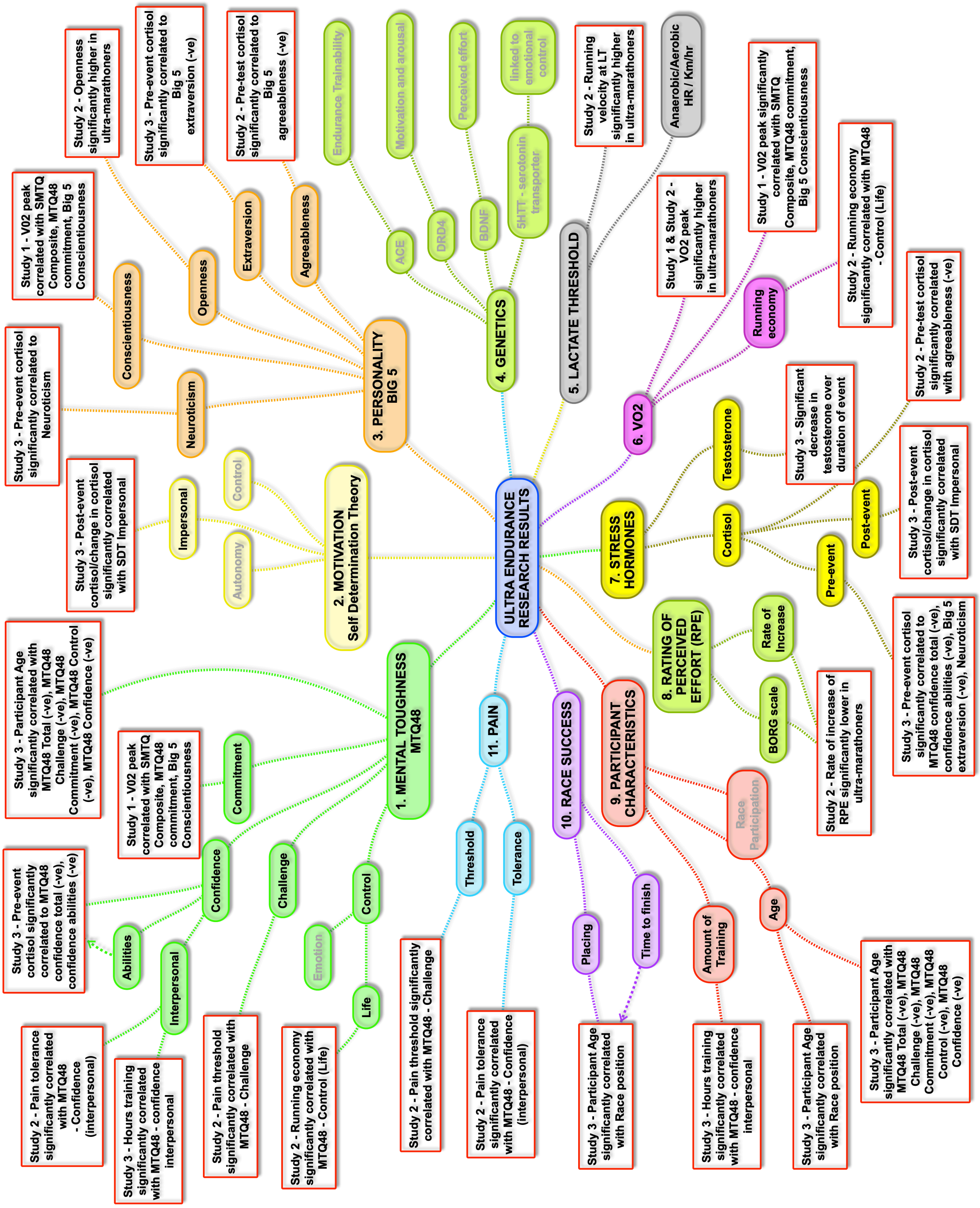
This is the first programme of research to use an interdisciplinary approach, to quantify, and compare, psychological and physiological factors, in both trained ultra-marathoners and un-trained non-ultra-marathoners, within multiple environments using a range of research designs, which include, (a) controlled experimental laboratory settings, and (b) in the field during participation in a competition.

The discoveries from this thesis make two unique contributions to the sport and exercise science of ultra-endurance. Firstly, Studies 1, 2 and 3, examined the relationships between psychological factors, including mental toughness, motivation and personality, and physiological factors measuring endurance performance. This research identified that ultra-marathoners achieved higher levels of endurance as a result of physiological adaptions following increased training regimes, are identifiable by their openness to new experiences, according to Study 2, but not their mental toughness, or motivation, and that the physiological factors measured did not predict race success. Study 3 examined limited physiological measures at multiple time points and identified that some psychological characteristics impact the stress hormone, cortisol. Figure 7.1 identifies psychophysiological measures and associated findings from this programme of research: Studies 1, 2, and 3, findings are boxed in red.

A major strength of this programme of research arises from the interdisciplinary research methodology that combined multiple psychological and physiological outcome measures across 3 studies. Psychological factors included a varied set of measures, including MTQ48 for mental toughness, Big 5 Personality Inventory, and SDT GCOS for motivation, and physiological factors including running economy, stress hormones, lactate threshold, maximal oxygen uptake, RPE, pain tolerance and threshold, and polymorphism and expression measures of 4 selected genes.

Figure 7.1

Psychological and Physiological Measures and Corresponding Findings



7.3. Psychophysiological Integration and Summary of Research Findings

Studies 1 to 3 identified that the ultra-marathoner is open to new experiences and that mental toughness is associated with running economy, pain threshold and tolerance, and supports achieving individual limits.

Mental toughness

In support of the null hypothesis of Studies 1 and 2, a higher score in mental toughness does not identify ultra-marathoners and is not a prerequisite for the successful participation or completion of an ultra-marathon race. Across all participants, mental toughness was associated with markers of increased aerobic fitness. Study 1 identified large, statistically significant positive correlations between maximal oxygen uptake, and commitment, overall mental toughness and conscientiousness, whilst Study 2 reported a large statistically significant positive relationship between increased levels of mental toughness and running economy, pain threshold and tolerance. Collectively these data provide evidence that, independent of whether or not an individual competes in ultra-running events, personality traits, and attributes of mental toughness are associated with maximising aerobic potential, but do not preclude successful ultra-marathon participation or completion.

Personality

In support of the alternative hypothesis, the findings of Study 1 and 2 did not detect any evidence for significant differences between ultra-marathoners and non-ultra-marathoners in four of the Big 5 Personality traits: conscientiousness, extraversion, agreeableness and neuroticism. However, in partial support of existing literature (Kaiseler et al., 2012, 2017), Study 2 reported that ultra-marathoners were identified by an increased openness to experience when compared to non-ultra-marathoners who were low in aerobic fitness.

Motivation

In support of the null hypothesis, analysis of the findings from Studies 1 and 2, suggest motivation, as defined by the SDT GCOS, with its causality orientations, autonomy, control and impersonal, does not differentiate the ultra-marathoner as more intrinsically or extrinsically motivated from the non-ultra-marathoner. Furthermore, in Study 3, race success was also not predicted by causality orientations, therefore the application of SDT, or the SDT GCOS, to interpret differences between ultra-marathoners and non-ultra-marathoners appears to be unsuitable.

Aerobic markers

Ultra-marathoners, in both Studies 1 and 2, were identified as having an increased maximum rate at which oxygen can be taken up, transported and utilised for running, which is consistent with existing research, and identified with increased aerobic performance (Schnohr et al., 2015; Bassett & Howley, 2000). Heightened fitness, as measured through maximal oxygen uptake, appears to be consistent with increased training, and associated physiological adaptations, rather than the psychological factors measured (Billat, 1999; Rønnestad & Mujika, 2013; Rowland, 2009). However, as previously discussed, maximal oxygen uptake may not equate directly to ultra-marathon performance, with other factors likely to impact, including running economy and the ability to maintain the highest percentage of the $\dot{V}O_{2max}$, for longest duration of the event (Knechtle, 2010; 2015). More recently there have been challenges regarding the legitimacy of $\dot{V}O_{2max}$ as a practical measure of cardio-respiratory endurance, and whether it identifies the maximum ability to transport oxygen.

Physiological Stress

In contrast to previous research, no differences in measures of stress either prior to, and following, the aerobic testing, were observed between the ultra-marathoners and the non-ultra-marathoners in Study 2. Interestingly, participants from both the ultra-marathon and the non-ultra-marathon group, with increased levels of agreeableness, were observed to have reduced pre-race stress. This may be as a result of a tendency to be more cooperative, and less suspicious, resulting in lower levels of agitation. Study 3 in contrast, performed in the context of a competitive event, observed that participants who were mentally tough, extraverted, confident, with reduced measures of neuroticism, have lower pre-race stress. The lack of significant intra-individual change in cortisol, and the significant increase in testosterone, recorded prior to, and following, competition, was in contrast to previous research findings, though it has been recognised that other conflicting factors, including time of day, may affect results (Lac & Berthon, 2000; Tanner et al., 2013). Surprisingly, the results of a Pearson Product Moment correlational analysis show that for all participants there is a significant positive relationship between believing attainment of a goals is outside of control, rather than taking responsibility for one's own behaviour, and the increase in the size of the change in cortisol over the course of the ultra-marathon. This increase in cortisol may be linked to the individual's preparation for action, which over the length of an endurance race, could be ongoing, and prolonged, and the size of the increase may indicate reduced resilience to a situation of potential stress (Kivlighan et al., 2005).

The effects of stress hormone changes on successful performance in endurance racing, and conversely the impact of events on cortisol and testosterone, remains unclear as a result of this study. Researchers have suggested that increased cortisol, pre-competition, may be an adaptive response to endurance training and is beneficial to athletes to meet the demands of a race

(Kivlighan et al., 2005). However, a reduction in pre-race stress may benefit participants in terms of diminished interruption to mental preparation, though this was not evidenced by improved running times in this study. To avoid speculation, address a lack of clarity, and better understand the co-dependency between hormone levels and aerobic capacity, further research into physiological stress in endurance races is warranted.

Genetics

Approximately 21,000 protein coding and 23,000 non-protein coding genes (Willyard, 2018) have been identified in the human genome, and despite research having identified 200 gene variants with performance phenotypes, little is known about the influence of genetic polymorphisms on performance in sport (Castilha et al., 2018). Possibly as a result of research costs and duration, testing has typically focussed on a small number of genes, with the ACE gene being the most widely studied gene for endurance performance (Ash et al., 2011). In contrast to the findings of Montgomery et al. (1998), no significant differences were identified in the polymorphism of ACE gene allele of ultra-marathoners and non-ultra-marathoners. However, results have been inconsistent, more recent studies have failed to identify differences between endurance athletes, and matched controls, suggesting that it is not likely that the ACE II genotype provides an advantage in endurance running (Ash et al., 2011; Papadimitriou et al., 2018). Study 2 found no support for existing literature that suggests the serotonin transporter gene (5HTT) may be linked with the ability to control emotion, the brain-derived neurotrophic factor (BDNF) may directly impact perceived effort during aerobic activity, and the dopamine receptor gene (D4DR) appears to affect the dopaminergic system, involved in both motivation, arousal and risk-taking behaviour. Indeed, Study 2, found no significant differences between RNA expression associated with the genes, 5HTT, BDNF and D4DR, in ultra-marathoners and non-ultra-marathoners, suggesting that the participation and completion of an ultra-marathon is not conditional on any of these 4 single genes (Lippi et al., 2009; Eichhammer et al., 2005; Carpenter et al., 2011). Researchers have established both a strong heritability of personality traits and gains in aerobic capacity (Castilha et al., 2018; Horsburgh et al., 2009; Sarzynski et al., 2017), as a result of endurance training, and identified multiple genes that can impact sporting performance, however further investigation is warranted to identify the genetic predisposition of an individual to succeed in ultra-marathons. Any future research should consider that a single gene test may not provide a sufficient indication of the genetic predisposition of an individual to succeed in ultra-endurance events and should be aligned with larger hypothesis-free genetic testing. Furthermore, the testing protocol should clearly be aimed at either testing transient, or long-term upregulation, or downregulation of the genes' expression (Sarzynski et al., 2017).

Pain

In Study 2 there was no difference in the quantification of pain threshold or pain tolerance, between ultra-marathoners, and non-ultra-marathoners. This may in part be a result of the challenges associated with objectively identifying the point at which stimulation, in this case immersion in ice, becomes painful, and ultimately intolerable. According to Osborn and Rodham (2010), as a result of the large number of contextual factors that are likely to impact the subjective, multi-dimensional nature of pain perception, it may be more appropriate to make use of qualitative research to uncover and explore the key aspects of the experience of pain. The discomfort experienced during a race may differ considerably along with an individual's ability to tolerate it, between race conditions, state of mind or health of the individual, and between a race setting and a laboratory. Furthermore, research suggests that training, and its intensity, can in turn impact pain tolerance in muscles (O'Leary et al., 2017).

Race performance

Collectively the findings show that no single measure in Study 3, other than age affected the time taken to complete an ultra-marathon race. Mental toughness, personality and motivational measurements did not predict either race success or the changes in cortisol levels, though motivation was associated with overall changes in testosterone. The decline in race performance with age was consistent with previous studies that identified a related decline in physiology, and theorised that reduced endurance performance is primarily a result of an age-related decline in $\dot{V}O_{2max}$ along with decreased muscle mass (Knechtle et al., 2012).

Rating of Perceived Exertion

Analysis of the findings from Study 2, are in support of existing research, and suggest that the rate at which RPE increases is reduced in the aerobically trained ultra-marathoner. As discussed in Section 2.4, it has been theorised that exercise intensity is regulated by perceived exertion and ensures homeostasis is maintained within limits (Eston, 2012). The data provides support for the theory that RPE is predictive of the duration of aerobic exercise prior to cessation due to exhaustion, and, is (a) in line with the psychobiological model, that predicts increasing RPE leads to reduced endurance performance (Marcora et al., 2009), and (b) the central governor model, that speculates that it forms part of a feedforward control model limiting exercise (Crewe et al., 2008).

The results of Studies 1, 2 and 3 are summarised in Table 7.1. The first column identifies the psychological factors, while the second and third columns summarise the relationship with success of the ultra-marathoner, and its effect on aerobic fitness in the general population, respectively.

Table 7.1
Psychological Factors and their Effect on Success in Ultra-marathoners, and Aerobic Limits in the General Population

Factor	**Affect success in ultra-marathoners**	**Affect aerobic fitness /limits in everyone**
Mental Toughness (according to MTQ48)	Mental toughness and constituent factors do not identify the ultra-marathoner	Mental toughness factors are predictive of aerobic success i.e. $\dot{V}O_{2peak}$ / Running economy
Personality Big-5 (openness, conscientiousness, neuroticism, extraversion, agreeableness)	Openness identifies the ultra-marathoner (Study 2 only)	The Big 5 personality traits are not predictive of aerobic success (as measured by either $\dot{V}O_{2peak}$, running economy, lactate threshold)
Motivation	Intrinsic/ extrinsic motivation does not identify the ultra-marathoner	Intrinsic/ extrinsic motivation is not predictive of aerobic success (as measured by either $\dot{V}O_{2peak}$, running economy, lactate threshold)
Selected Genes (ACE Gene allele, 5HTT, BDNF, D4DR)	Genes selected do not identify the ultra-marathoner	Selected genes are not predictive of aerobic success (as measured by either $\dot{V}O_{2peak}$, running economy, lactate threshold)
Rate of increase of RPE	Ultra-marathoners identified by a lower rate of increase of RPE	A reduced rate of increase of RPE is indicative of increased $\dot{V}O_{2peak}$

7.4. Theoretical Impact of Psychological Models on Interpreting Endurance

This thesis does not reject the widely held view that mental toughness is an important, multidimensional, psychological construct related to performance excellence in a multitude of sporting environments. However, analysis of the findings does question the requirement to be mentally tough to succeed in an endurance event, such as an ultra-marathon. In contrast to previous research, this thesis therefore finds that being high in mental toughness, as measured by the MTQ48, is not a prerequisite to either participate, or perform well, in ultra-marathons (Connaughton et al., 2008; Gucciardi et al., 2016; Perry et al., 2013; Thelwell et al., 2010).

The MTQ48 model of mental toughness, and the SDT GCOS model of motivation do not identify the ultra-marathoner, nor measure factors involved in successful performance during an event. Alongside a number of existing concerns raised regarding the underlying conceptual model of the MTQ48, recent literature has challenged the applicability of the MTQ48 for use with athletes at differing levels of athletic experience (Anthony et al., 2016; Vaughan et al., 2017). Researchers have speculated that the MTQ48, is a general measure of mental toughness, and consequently may be less appropriate to specific populations that require language more apposite to the context (Gucciardi et al., 2016). This may explain why ultra-marathoners, a defined athletic sample, were not identified by their mental toughness, whilst mental toughness was identified with improved aerobic fitness in the entire population. Gucciardi (2017) theorised that mental toughness is state-like, rather than trait-like, and can fluctuate over time depending on the context and, internal and external demands. Consequently, the development of mental toughness, and aerobic fitness, warrants further research to better understand the direction of causation. The failure to identify ultra-marathoners as a result of mental toughness may, in part, be an issue of context. Mental toughness may be specific to an environment or situation, and ignorance of this contextual factor may lead to contradictory results (Crust, 2008, 2008a ; Gucciardi, 2017; Gucciardi & Gordon, 2013). Jones et al., (2002) has suggested that a mentally tough sports person has an advantage over opponents by providing protection to the individual and ensuring an ability to cope better with the demands of sport, whilst maintaining consistency in determination, focus and having control whilst under pressure. The present findings clearly indicate that during a race, mentally tough ultra-endurance runners may not be more likely to reach increased levels of physiological stress and realise their physical potential.

Further concerns have been raised regarding both the assumption that elite athletes are, by the very nature of being at the top of their game, mentally tough, and that those interviewed have a full, and consistent, conception of mental toughness, and, the belief that success is only defined as beating the opponent (Crust, 2008; Jones et al., 2002, 2007; Gucciardi et al., 2009; Thelwell et al., 2005). There is also a risk associated with the assumption that mental toughness and success are strongly co-dependent and mental toughness is an indication of superior athletic ability rather than the capacity to overcome the challenges faced during training and competition. This issue is further compounded by both a lack of conceptual clarity surrounding the meaning, or definition of mental toughness, and uncertainty regarding the multidimensionality of mental toughness, its permanence over time, direct assessment, and variation across situations (Clough et al., 2002; Crust, 2008, 2008a; Gucciardi et al., 2014).

In contrast, to the vast majority of studies, a key strength of this programme of research is the focus on non-elite athletes, and the lack of assumption regarding participants' level of mental toughness. Recent research, also involving non-elites, measured mental toughness in recreationally active participants; analysis of findings suggested the positive impact of long-term endurance training, and competition, experience on mental toughness (Marshall et al., 2017). The results of research into personality linked to sports performance remain contradictory, with evidence from population-based studies difficult to generalise, and associations between personality and success in sport unconvincing (Allen et al., 2011; Kaiseler et al., 2017). It therefore remains unclear, as a result of this thesis, and previous research, the size, or type of impact personality has on ultra-marathoners, their training, or performance in competition.

This programme of research suggests that either, in contrast to existing literature (Hanson et al., 2015), increased intrinsic motivation is not a characteristic of an ultra-marathoner, or that it is a characteristic, and that both ultra-marathoners and non-ultra-marathoners are equally high. It can be speculated, based on the findings of Study 1, 2, and 3, the Self-determination Theory, either does not provide a framework for studying motivation in ultra-marathoners, or that ultra-marathoners and non-ultra-marathoners are, in contrast to existing research, homogeneous in both, the three causality orientations, autonomy, control and impersonal measures, and the innate psychological needs of relatedness, competence and autonomy (Deci & Ryan, 1985; Ryan & Deci , 2017). It may be theorised that ultra-marathoners are no more, or less motivated as a result of opportunities for choice and determination, and do not focus on social norms or pressures, or find environments uncontrollable or demotivating (Deci, 1985; 2000; 2008; 2017).

Study 2 identified the personality trait ‘openness’ as being a predictor of success in an ultra-marathon and suggests there are benefits to being open to new experiences, possibly including the ability to tackle issues that arise, rather than the use of avoidance strategies. According to Hughes et al. (2003) attempts to define personality profiles in athletes and non-athletes have been inconsistent. However, in their investigation into the personality profiles of participants in a 100-mile race in the Alaskan wilderness, racers scored significantly higher in both extraversion and openness. Consistent with the present findings, Hughes and colleagues suggest that race participants choose novel experiences that provide challenge, possibly involving more risk, than the norm sample. The failure to identify differences in the remaining personality traits, of conscientiousness, extraversion, agreeableness and neuroticism, between the two groups, is inconsistent to previous research, and leads to speculation that an ultra-marathoner is similar in personality to a non-ultra-marathoner (Allen et al., 2011; Kaiseler et al., 2017**).** There is limited research regarding the impact of personality traits in endurance events, and research is warranted to better understand how the benefits of openness can be strengthened.

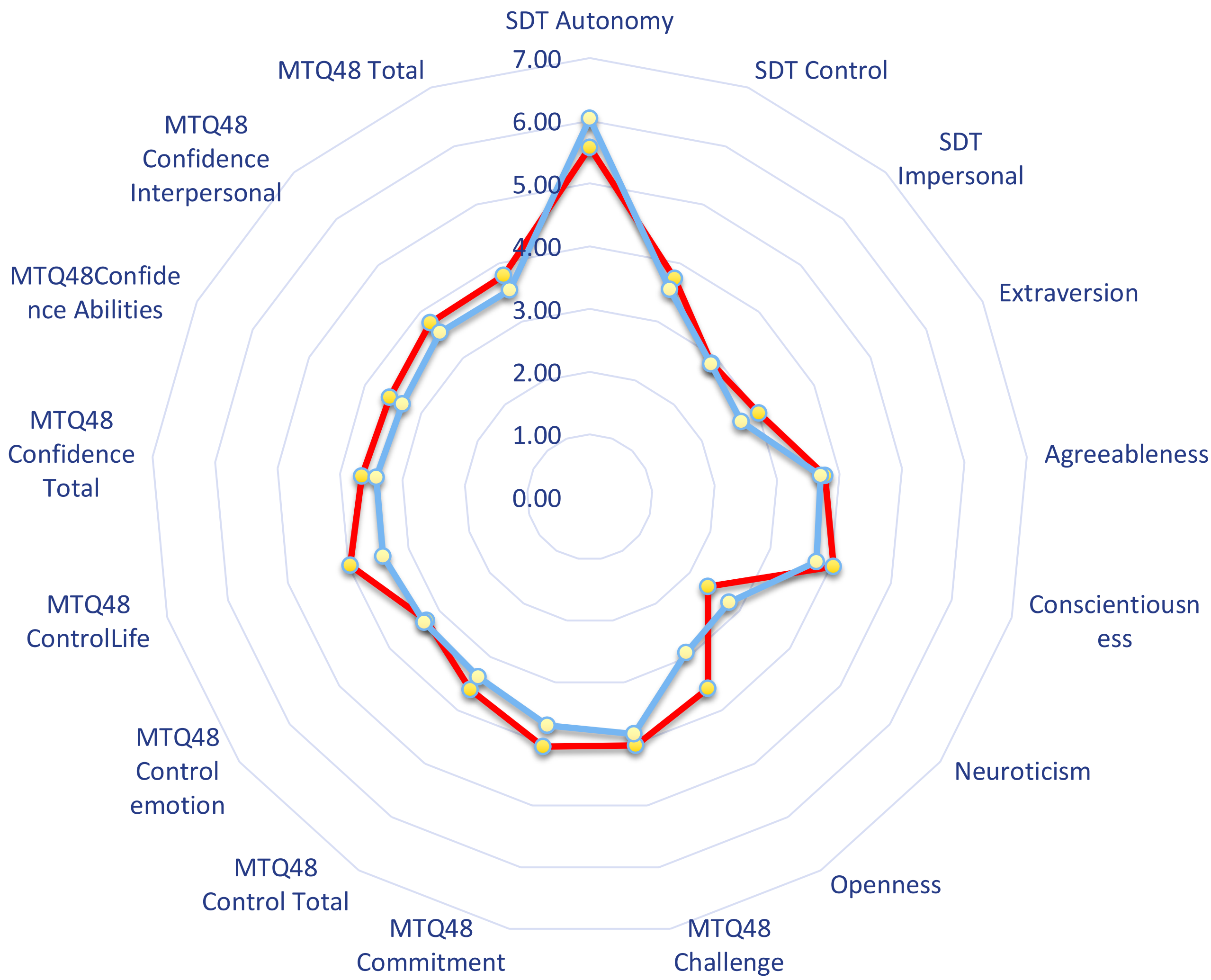
The findings of the present research are consistent with both the Central Governor Model, and the Psychobiological Model (Marcora & Staiano, 2010; Noakes, 2007) that perception of effort, or RPE, is a predictor of time to exhaustion. Analysis of the data suggests that the ultra-marathoner has a reduced rating of perception of fatigue, or RPE, and an increased time to volitional exhaustion. Further research is required to better understand the models of aerobic failure, (a) Noakes' (2007) theory that RPE is generated by the brain to ensure that increasing levels of discomfort cause exercise to be terminated prior to homeostatic failure, or (b) Marcora & Staiano's (2010) theory that exhaustion is a type of disengagement from the aerobic task in response to the willingness to continue the effort required.

Interdisciplinary Optimum Balanced Performance Model of Endurance Success in Ultra-marathoners

It may be speculated from this programme of research that the optimum behaviours for ultra-marathon training and racing result from a balance of psychological attributes including mental toughness, motivation and personality (Connaughton et al., 2008; Gucciardi & Gordon, 2013; Gucciardi et al., 2016; Jones et al., 2002; Perry et al., 2013; Thelwell et al., 2010). Different and diverse balances, involving these factors, may be beneficial to each sport, context, or situation (Clough & Strycharczyk, 2012). The present research focussed on the differences between ultra-marathoners and non-ultra-marathoners and did not facilitate the examination of the profiles of the runners, and the intra-relationships between psychological attributes. More extreme scores in individual, or grouped attributes, may lead to detrimental behaviour, whilst a more balanced profile may result in a positive, fruitful, outcome for the ultra-marathoner, in both the sport, and in closely impacting, and supporting areas, including work and family. A balance of personality traits, avoiding extremes, such as neuroticism and extraversion, may lead to an individual using a moderate approach to training and racing, potentially avoiding injury with unplanned training increases, and a more measured approach to races that will last many hours. Figure 7.2 presents an overview of the average psychological scores for ultra-marathoners, and low aerobic participants, red and blue lines respectively, from Study 2.

Figure 7.2

Patterns of Psychological Measures from Study 2



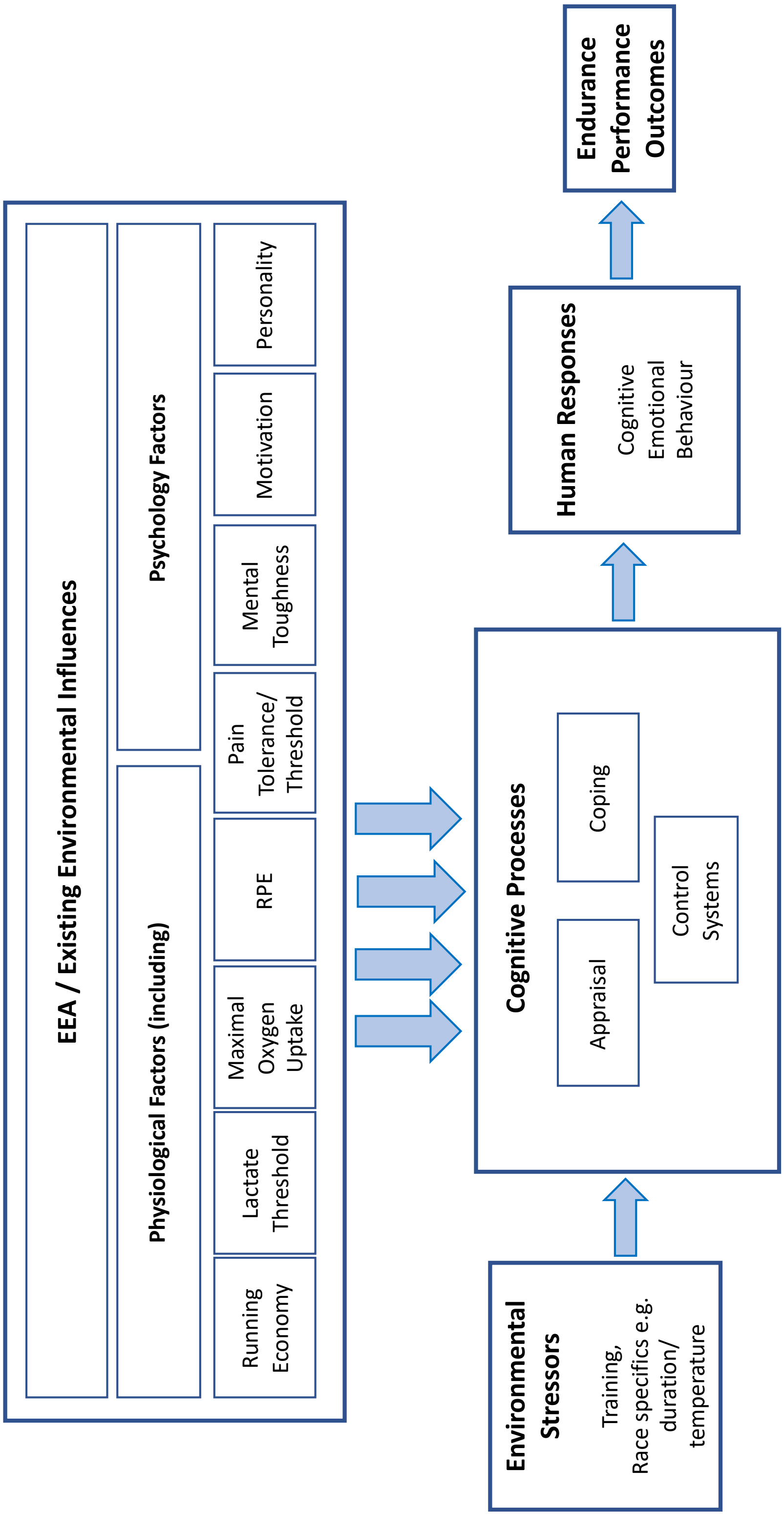
The patterns of psychological measures between the ultra-marathon group and the low aerobic group are similar, but average mental toughness, and openness values are lower, whilst the average neuroticism value is higher, in the low aerobic group. Psychological measures, and intra-relationships, may potentially, collectively identify ultra-marathoners. Further research is recommended that profiles ultra-marathoners versus non-ultra-marathoners to help understand the intra- and inter- individual characteristics.

Building on the work of Fletcher (2005) (Figure 2.2), and analysis of the results of Studies 1, 2, and 3, this author proposes an interdisciplinary, Optimum Balanced Performance Model of Endurance (see Figure 7.3). Fletcher's (2005) facet model proposes that mental toughness moderates the appraisal of, and coping with, stressors, and ultimately impacts performance. The proposed interdisciplinary, Optimum Balanced Performance Model of Endurance develops the idea of mental toughness moderating stress consistent with previous research (Sheard, 2013) and speculates the integrated and moderating role of psychological factors, including mental toughness, personality and motivation and their theoretical relationship with performance. These psychological factors, along with physiological factors, including maximal oxygen uptake, lactate threshold, running economy, RPE, stress hormones and genetic factors moderate the relationship between environmental stressors, such as race distance and conditions, and the cognitive, emotional and behavioural responses that affect endurance performance outcomes.

According to this model (Figure 7.3) the cognitive, emotional and behavioural responses that impact both participation and performance in ultra-marathons are therefore: determined by (a) psychological and physiological factors, adapted as a result of genetic inheritance, (b) along with the psychological, physiological and epigenetic effects during the development of the *individual*, and (c) moderated by cognitive processes. Such processes are likely to include appraisal and coping mechanisms, along with control systems balancing sensations of fatigue (RPE) with expected fatigue, to ensure homeostasis and event completion.

Figure 7.3

Interdisciplinary Optimum Balanced Performance Model of Endurance Success in Ultra-marathons



Evolved Adaptations to Endurance

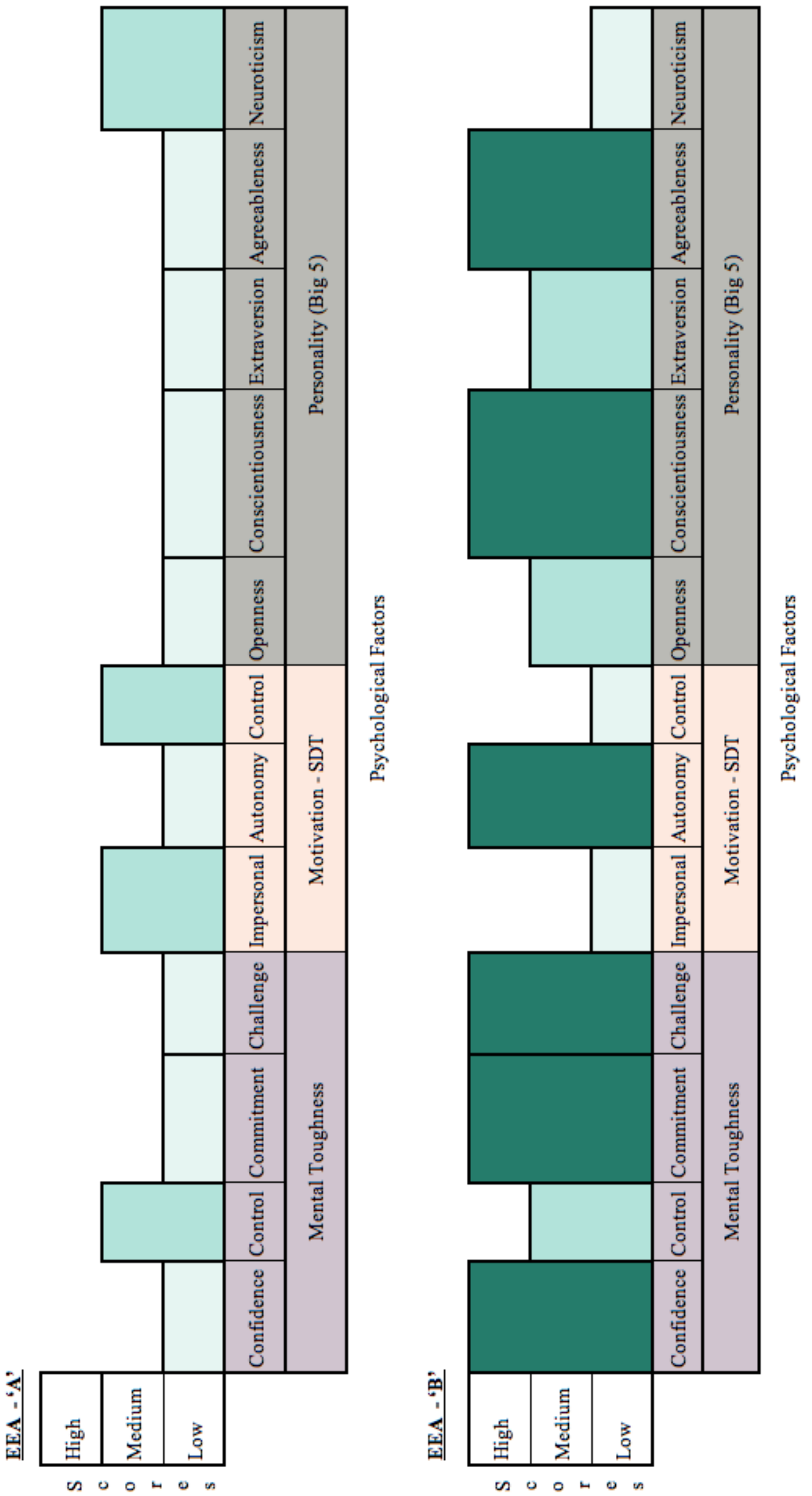
Chapter 2 reviewed the widely held theory that homo-sapiens are, as a species, designed for endurance, with highly developed, specialised features that provided a significant contribution to the evolution of the human form (Bramble & Lieberman, 2004; Brooks, 2012; Hawley et al., 2014; Schulkin, 2016). If physiological adaptations evolved to facilitate endurance, and, if according to evolutionary psychologists, psychological traits are important adaptations designed to solve challenges faced by our ancestors (Buss, 2009; 2009a), then it may be speculated that the psychology of modern humans is, in part, a consequence of evolutionary adaptations for endurance.

According to evolutionary psychologists, at birth the human mind is neither a blank slate, nor a general-purpose computer, but is instead a set of highly specific, and evolved adaptive programmes (Cosmides & Tooby, 2013). Each mechanism within the brain has been shaped through natural, and sexual, selection, to solve the problems encountered within the environment of evolutionary adaptedness (EEA). Our ancestors evolved to survive over 4 million years of living as a nomadic hunter-gatherer, and only within the last 10,000 years have we developed a more sedentary, less nomadic lifestyle. Natural selection overcame many problems to ensure the survival of the species, adapting focussed, content-rich, highly specialised architecture that meet specific information-processing requirements: cooperation with our kin, dealing with our enemies, communication, including both language and non-verbal, identification and location of food, hunting, mate selection and avoiding infectious disease and poisonous food (Buss, 2009; 2009a; Cosmides & Tooby, 2013). Multiple adaptive mechanisms may also have evolved specifically for endurance.

Collectively, the 3 studies suggest that only the psychological trait of *openness* identifies the ultra-marathoner. Therefore, either there is a single psychological measure that predicts endurance success within the study population, or there is one, or many combinations of measures that have evolved to facilitate endurance performance. Figure 7.4 considers the hypothetical, potential of multiple sets of psychological measures, or optimum profiles, adapted to different, and unique, environments of evolutionary adaptation (EEA).

Assuming an organism's ability to increase the frequency of their genes in the next generation may be a result of one, or more, psychological adaptations to the EEA. Such adaptations, that offered an advantage, would therefore 'proliferate' in subsequent generations, and may be different between EEA's. As an example, EEA 'A' may have been a time when food was in plentiful supply, whilst EEA 'B' may have been during an extended period of drought, climatic extremes and human migration. Very different psychological measures could have adapted to meet the endurance requirements of each environment. As a result, though endurance may have been crucial to the survival of the human species, there may be no one trait, or set of traits, that predicts successful performance.

Figure 7.4
'Hypothetical' example of Measures Best Suited for Different Environments of Evolutionary Adaptation (EEA)



In summary

In order to provide a deeper understanding of the sport and exercise science of ultra-marathon success, it is necessary to adopt a psychophysiological approach to develop models that combine methods, theories and concepts (Balagué et al., 2017). Psychological factors should not be analysed out of context, but within an interdisciplinary model, including techniques, expertise and knowledge from fields as diverse as psychology, genetics, physiology, cognitive science and evolutionary biology. Continued interdisciplinary research is likely to both expand and refine our understanding, irrespective of scientific field and, facilitate the development of models that are testable and predictive.

This programme of research suggests an Optimum Balanced Performance Model of Endurance Success and the subsequent benefits of adopting an interdisciplinary approach. The psychophysiological data suggests that ultra-marathoners and non-ultra-marathoners are largely homogeneous, other than measures of aerobic fitness, in response to significant aerobic training, and an openness to new experiences. It is therefore predicted from this body of research that, with suitable training and an absence of health problems, any individual could become a competitor in an ultra-marathon. This is perhaps unsurprising given our evolutionary background. If, as discussed in Chapter 2, endurance running was important in the evolution of early hominins, with key physiological adaptions evolving over millions of years to benefit long distance running, it can therefore be the case that we have also evolved psychologically to facilitate the performance feats of endurance (Bramble & Lieberman, 2004; Hawley et al., 2014; Schulkin, 2016). However, the possibility of identifying measurable evidence of this inheritance, is limited, with reliance likely to be placed on genetics to provide further clarity regarding the DNA underpinning existing and prior phenotypes. Evolutionary psychology has had some success in explaining psychological traits as important evolutionary outcomes, with adaptations designed to solve the problems faced by our ancestors and may provide some insight into the shared pre-prerequisites for endurance activities (Buss, 2009, 2009a). The psychology of modern man and woman may therefore be a consequence of adaptations evolved to enable, or because of, endurance related activities.

7.5. Limitations, and Future Work Required in this Area

The present programme of research included an extensive, but not exhaustive, set of psychophysiological measures. Further interdisciplinary research is encouraged to extend testing to include other factors that may influence performance in endurance events, including: (a) mental fatigue; (b) the capacity to maintain the highest fraction of maximal oxygen uptake over the duration of the competition; (c) energy cost and running economy; (d) previous race experience; and (e) their interaction with mental toughness, motivation and personality.

Studies 1 and 2 focussed on the differences between ultra-marathoners and non-ultra-marathoners and did not facilitate the examination of the profiles of the runners, and the intra-relationships between psychological attributes. Further research is recommended that profiles ultra-marathoners, and elite ultra-marathoners, versus non-ultra-marathoners to help understand the intra- and inter- individual characteristics. Lack of differences in mental toughness may be a result of the validity, and accuracy, of quantifying mental toughness via the self-report nature of the MTQ48 and contextual influences. Future research is warranted to identify ecologically valid, objective measures of mental toughness, affected by environmental and physiological factors. This may lead to an improved understanding of mental toughness, within context, not only situational and the environmental stressors, but also in relation to the physiological state of the body.

A strength of this programme of research is that all factors were measured quantitively, allowing comparison both between groups of ultra-marathoners and non-ultra-marathoners, and between psychological and physiological measures. However, future research is warranted to examine individual experiences of running an ultra-marathon using qualitative collection methods and offer an insight into cognitive processes including attentional focus, perception of effort and explore aspects of the experience of pain.

Due to time and resource considerations Studies 1 and 2 were restricted to testing 4 genes. There is a need to extend testing, using hypothesis-free, genome-wide investigations, along with their expression, to identify the genetic predisposition of an individual to succeed in ultra-endurance events.

It should be noted that two of the three studies were performed under laboratory conditions, which may not be representative of success in the context of an endurance challenge. Research into ultra-marathoners to push themselves to their limits, in situ, has been largely overlooked, and it is suggested that future studies undertake quantifying stress hormone changes in varying race conditions, including multi-day events, 24-hour track, mountain, desert and arctic events, and compare with both times to complete the race and psychological factors.

In this programme of research, maximal oxygen uptake, along with lactate threshold were used as an indication of aerobic fitness. There is a need to further determine the extent to which termination of the $\dot{V}O_{2peak}$ testing may be driven by motivational factors, rather than physiological ones.

The interdisciplinary Optimum Balanced Performance Model of Endurance Success is speculated in response to analysis of the findings from the present research and needs to be developed to predict aerobic success in ultra-marathoners. Further testing is recommended to identify all factors that may impact performance in ultra-marathon events, and the interaction between measures, including a general need to determine the extent to which the brain regulates exercise and the extent to which mental fatigue, and perceived exertion impairs physical performance.

APPENDICES

8. Appendices

8.1. Psychology and Physiology in Endurance – Participant Questionnaires

8.1.1. Participant Health Questionnaire

Title: Identification of the psychological and physiological factors that enable endurance performance success in trained ultra-marathoners

The aim of this study is to identify the psychological and physiological factors that enable endurance performance success in trained ultra-marathoners, as evidenced by increased $\dot{V}O_{2peak}$. Psychological factors including mental toughness, personality traits, motivation and attentional focus along with physiological factors such as the stress hormone, cortisol, genetic status, lactate threshold and ability to tolerate pain will be measured.

In order to identify suitable participants to participate in the above study, and to ensure their health and well-being please can you answer the below questions to the best of your knowledge.

All data gathered will be treated with the utmost confidence and any identification of participants personal details will be removed prior to publication as required under Data Protection legislation. However, it is important to highlight Freedom of Information legislation that allows access to non-personal or generalised data.

Health Questionnaire

Please review these statements and answer based on past/current health issues:

Question Number	Question	Answer YES/NO
H1	History of heart problems (ie. chest pains, heart murmur, or stroke)	
H2	Diabetes	
H3	Asthma	
H4	Cancer (other than skin)	
H5	Seizures, seizure medication, neurological problems or dizziness	
H6	High blood pressure	
H7	Back problem, joint or muscle disorder still affecting you	
H8	Recent surgery (last 12 months)	
H9	Physician's advice not to exercise	
H10	History of high cholesterol	
H11	Hernia or any condition that may be aggravated by exercise	
H12	Family history of coronary heart disease	
H13	Doctor, or any other health advisor, ever said that you have a heart condition and that you should only do physical activity recommended by a doctor	

H14	Feel pain in your chest when you do any physical activity	
H15	Lose balance because of dizziness or do you ever lose consciousness	
H16	Bone or joint problems that could be made worse by a change in your physical activity level	
H17	Prescribed any medication for your blood pressure or a heart condition	
H18	Current, or pre-existing, injury that would prevent you from taking part in exercise on a treadmill	
H19	Know of any reason why you should not do physical activity or take part in this test	

If you require any further information re this study, please do not hesitate to contact myself Jeremy Sutton either by phone or e-mail on (07909996420) or sutton-j@email.ulster.ac.uk

8.1.2. Psychology and Physiology in Endurance – Training Questionnaire

Participant Endurance Training Questionnaire

Title: Identification of the psychological and physiological factors that enable endurance performance success in trained ultra-marathoners

The aim of this study is to identify the psychological and physiological factors that enable endurance performance success in trained ultra-marathoners as evidenced by increased $\dot{V}O_{2peak}$. Psychological factors including mental toughness, personality traits, motivation and attentional focus along with physiological factors such as the stress hormone, cortisol, genetic status, lactate threshold and ability to tolerate pain will be measured.

In order to identify suitable participants to participate in the above study, and to ensure their health and well-being please can you answer the below questions to the best of your knowledge.

All data gathered will be treated with the utmost confidence and any identification of participants personal details will be removed prior to publication as required under Data Protection legislation. However, it is important to highlight Freedom of Information legislation that allows access to non-personal or generalised data.

Training Questionnaire

Question Number	Question	Answer
T1	How many hours and minutes of planned cardio-vascular exercise do you perform on average a week? Please specify the names of the activities?	e.g. X hours & Y minutes– Running X hours & Y minutes- Swimming X hours & Y minutes- Cycling
T2	When was the last time you completed an ultra-marathon i.e. a running race greater than 26.2 miles? If never, please state 'N/A'	X months ago,
If you answered 'N/A' for question T2, then continue to question T5		
T3	How many miles was the last ultra-marathon race you took part in? Did you complete the entire race? If NO how many miles did you complete? How long did it take you to complete the distance?	X miles Yes/No X miles X hours & Y Minutes
T4	How many ultra-marathons have you completed? When was your first ultra-marathon	X number DD/MM/YYYY

T5	Are you currently training for an ultra-marathon? What is it called? When is it? How many miles are in the race?	Yes/No Name of event Day/Month/Year X miles
T6	How many miles are you running on average per week? (i.e. an average week over the course of the last month)	X miles
T7	How many miles is your longest run per week? (i.e. an average week over the course of the last month)	X miles

If you require any further information re this study, please do not hesitate to contact myself Jeremy Sutton either by phone or e-mail on (07909996420) or sutton-j@email.ulster.ac.uk

8.2. Psychological Tests

8.2.1. Sport Mental Toughness Questionnaire (SMTQ) item wording (Sheard, 2013)

Question number	Questions	Very True	Mostly True	A little True	Not at all True
1	I interpret threats as positive opportunities	A	B	C	D
2	I have an unshakeable confidence in my ability	A	B	C	D
3	I have qualities that set me apart from other competitors	A	B	C	D
4	I have what it takes to perform well while under pressure	A	B	C	D
5	Under pressure, I am able to make decisions with confidence and commitment	A	B	C	D
6	I can regain my composure if I have momentarily lost it	A	B	C	D
7	I am committed to completing the tasks I have to do	A	B	C	D
8	I take responsibility for setting myself challenging targets	A	B	C	D
9	I give up in difficult situations	A	B	C	D
10	I get distracted easily and lose my concentration	A	B	C	D
11	I worry about performing poorly	A	B	C	D
12	I am over-come by self doubt	A	B	C	D
13	I get anxious by events I did not expect or cannot control	A	B	C	D
14	I get angry and frustrated when things do not go my way	A	B	C	D

Items 1-6 measure Confidence. Scores range from 6-24.
Items 7-10 measure Constancy. Scores range from 4-16
Items 11-14 measure Control. Scores range from 4-16.

Composite scores range from 14-56.

Items 1-8 are positively scored (i.e. A = 4, B = 3, C = 2, D = 1)
Items 9-14 are negatively scored (i.e. A = 1, B = 2, C = 3, D = 4)

8.2.2. MTQ48 (Crust & Clough 2005)

Please indicate your response to the following items by **circling one** of the numbers, which have the following meaning;

1 = strongly disagree; **2** = disagree; **3** = neither agree nor disagree; **4** = agree; **5** = strongly agree

Please answer these items carefully, **thinking about how you are generally**. Do not spend too much time on any one item.

YOUR NAME ____

Agree ⏩	⏪ Disagree				
1) I usually find something to motivate me	1	2	3	4	5
2) I generally feel in control	1	2	3	4	5
3) I generally feel that I am a worthwhile person	1	2	3	4	5
4) Challenges usually bring out the best in me	1	2	3	4	5
5) When working with other people I am usually quite influential	1	2	3	4	5
6) Unexpected changes to my schedule generally throw me	1	2	3	4	5
7) I don't usually give up under pressure	1	2	3	4	5
8) I am generally confident in my own abilities	1	2	3	4	5
9) I usually find myself just going through the motions	1	2	3	4	5
10) At times I expect things to go wrong	1	2	3	4	5
11) "I just don't know where to begin" is a feeling I usually have when presented with several things to do at once	1	2	3	4	5
12) I generally feel that I am in control of what happens in my life	1	2	3	4	5
13) However bad things are, I usually feel they will work out positively in the end	1	2	3	4	5
14) I often wish my life was more predictable	1	2	3	4	5
15) Whenever I try to plan something, unforeseen factors usually seem to wreck it	1	2	3	4	5
16) I generally look on the bright side of life	1	2	3	4	5
17) I usually speak my mind when I have something to say	1	2	3	4	5
18) At times I feel completely useless	1	2	3	4	5
19) I can generally be relied upon to complete the tasks I am given	1	2	3	4	5
20) I usually take charge of a situation when I feel it is appropriate	1	2	3	4	5
21) I generally find it hard to relax	1	2	3	4	5
22) I am easily distracted from tasks that I am involved with	1	2	3	4	5
23) I generally cope well with any problems that occur	1	2	3	4	5
24) I do not usually criticise myself even when things go wrong	1	2	3	4	5
25) I generally try to give 100%	1	2	3	4	5
26) When I am upset or annoyed I usually let others know	1	2	3	4	5
27) I tend to worry about things well before they actually happen	1	2	3	4	5

28) I often feel intimidated in social gatherings	1	2	3	4	5
29) When faced with difficulties I usually give up	1	2	3	4	5
30) I am generally able to react quickly when something unexpected happens	1	2	3	4	5
31) Even when under considerable pressure I usually remain calm	1	2	3	4	5
32) If something can go wrong, it usually will	1	2	3	4	5
33) Things just usually happen to me	1	2	3	4	5
34) I generally hide my emotion from others	1	2	3	4	5
35) I usually find it difficult to make a mental effort when I am tired	1	2	3	4	5
36) When I make mistakes I usually let it worry me for days after	1	2	3	4	5
37) When I am feeling tired I find it difficult to get going	1	2	3	4	5
38) I am comfortable telling people what to do	1	2	3	4	5
39) I can normally sustain high levels of mental effort for long periods	1	2	3	4	5
40) I usually look forward to changes in my routine	1	2	3	4	5
41) I feel that what I do tends to make no difference	1	2	3	4	5
42) I usually find it hard to summon enthusiasm for the tasks I have to do	1	2	3	4	5
43) If I feel somebody is wrong, I am not afraid to argue with them	1	2	3	4	5
44) I usually enjoy a challenge	1	2	3	4	5
45) I can usually control my nervousness	1	2	3	4	5
46) In discussions, I tend to back-down even when I feel strongly about something	1	2	3	4	5
47) When I face setbacks I am often unable to persist with my goal	1	2	3	4	5
48) I can usually adapt myself to challenges that come my way	1	2	3	4	5

8.2.3. Big 5 Personality Inventory – (John et al., 1991, 2008)

taken from http://www.ocf.berkeley.edu/~johnlab/bfiscale.php

How I am in general

Here are a number of characteristics that may or may not apply to you. For example, do you agree that you are someone who *likes to spend time with others*? Please write a number next to each statement to indicate the extent to which **you agree or disagree with that statement.**

1	**2**	**3**	**4**	**5**
Disagree Strongly	Disagree a little	Neither agree nor disagree	Agree a little	Agree strongly

I am someone who…

1. _____ Is talkative
2. _____ Tends to find fault with others
3. _____ Does a thorough job
4. _____ Is depressed, blue
5. _____ Is original, comes up with new ideas
6. _____ Is reserved
7. _____ Is helpful and unselfish with others
8. _____ Can be somewhat careless
9. _____ Is relaxed, handles stress well.
10. _____ Is curious about many different things
11. Is full of energy
12. _____ Starts quarrels with others
13. _____ Is a reliable worker
14. _____ Can be tense
15. _____ Is ingenious, a deep thinker
16. _____ Generates a lot of enthusiasm
17. _____ Has a forgiving nature

18. _____ Tends to be disorganized

19. _____ Worries a lot

20. _____ Has an active imagination

21. _____ Tends to be quiet

22. _____ Is generally trusting

23. _____ Tends to be lazy

24. _____ Is emotionally stable, not easily upset

25. _____ Is inventive

26. _____ Has an assertive personality

27. _____ Can be cold and aloof

28. _____ Perseveres until the task is finished

29. _____ Can be moody

30. _____ Values artistic, aesthetic experiences

31. _____ Is sometimes shy, inhibited

32. _____ Is considerate and kind to almost everyone

33. _____ Does things efficiently

34. _____ Remains calm in tense situations

35. _____ Prefers work that is routine

36. _____ Is outgoing, sociable

37. _____ Is sometimes rude to others

38. _____ Makes plans and follows through with them

39. _____ Gets nervous easily

40. _____ Likes to reflect, play with ideas

41. _____ Has few artistic interests

42. _____ Likes to cooperate with others

43. _____ Is easily distracted

44. _____ Is sophisticated in art, music, or literature

8.2.4. General Causality Orientation Scale (GCOS) – (Deci & Ryan, 1985)

The Scale (12-vignette version)

These items pertain to a series of hypothetical sketches. Each sketch describes an incident and lists three ways of responding to it. Please read each sketch, imagine yourself in that situation, and then consider each of the possible responses. Think of each response option in terms of how likely it is that you would respond that way. (We all respond in a variety of ways to situations, and probably most or all responses are at least slightly likely for you.) If it is very unlikely that you would respond the way described in a given response, you should circle answer 1 or 2. If it is moderately likely, you would select a number in the mid range, and if it is very likely that you would respond as described, you would circle answer 6 or 7.

For each question, answer as follows:

1	2	3	4	5	6	7
very unlikely			moderately likely			very likely

1. You have been offered a new position in a company where you have worked for some time. The first question that is likely to come to mind is:

a) What if I can't live up to the new responsibility?

b) Will I make more at this position?

c) I wonder if the new work will be interesting.

2. You have a school-age daughter. On parents' night the teacher tells you that your daughter is doing poorly and doesn't seem involved in the work. You are likely to:

a) Talk it over with your daughter to understand further what the problem is.

b) Scold her and hope she does better.

c) Make sure she does the assignments, because she should be working harder.

3. You had a job interview several weeks ago. In the mail you received a form letter which states that the position has been filled. It is likely that you might think:

a) It's not what you know, but who you know.

b) I'm probably not good enough for the job.

c) Somehow they didn't see my qualifications as matching their needs.

4. You are a plant supervisor and have been charged with the task of allotting coffee breaks to three workers who cannot all break at once. You would likely handle this by:

a) Telling the three workers the situation and having them work with you on the schedule.

b) Simply assigning times that each can break to avoid any problems.

c) Find out from someone in authority what to do or do what was done in the past.

5. A close (same-sex) friend of yours has been moody lately, and a couple of times has become very angry with you over "nothing." You might:

a) Share your observations with him/her and try to find out what is going on for him/her.

b) Ignore it because there's not much you can do about it anyway.

c) Tell him/her that you're willing to spend time together if and only if he/she makes more effort to control him/herself.

6. You have just received the results of a test you took, and you discovered that you did very poorly. Your initial reaction is likely to be:

a) "I can't do anything right," and feel sad.

b) "I wonder how it is I did so poorly," and feel disappointed.

c) "That stupid test doesn't show anything," and feel angry.

7. You have been invited to a large party where you know very few people. As you look forward to the evening, you would likely expect that:

a) You'll try to fit in with whatever is happening in order to have a good time and not look bad.

b) You'll find some people with whom you can relate.

c) You'll probably feel somewhat isolated and unnoticed.

8. You are asked to plan a picnic for yourself and your fellow employees. Your style for approaching this project could most likely be characterized as:

a) Take charge: that is, you would make most of the major decisions yourself.

b) Follow precedent: you're not really up to the task so you'd do it the way it's been done before.

c) Seek participation: get inputs from others who want to make them before you make the final plans.

9. Recently a position opened up at your place of work that could have meant a promotion for you. However, a person you work with was offered the job rather than you. In evaluating the situation, you're likely to think:

a) You didn't really expect the job; you frequently get passed over.

b) The other person probably "did the right things" politically to get the job.

c) You would probably take a look at factors in your own performance that led you to be passed over.

10.You are embarking on a new career. The most important consideration is likely to be:

a) Whether you can do the work without getting in over your head.

b) How interested you are in that kind of work.

c) Whether there are good possibilities for advancement.

11. A woman who works for you has generally done an adequate job. However, for the past two weeks her work has not been up to par and she appears to be less actively interested in her work. Your reaction is likely to be:

a) Tell her that her work is below what is expected and that she should start working harder.

b) Ask her about the problem and let her know you are available to help work it out.

c) It's hard to know what to do to get her straightened out.

12. Your company has promoted you to a position in a city far from your present location. As you think about the move you would probably:

a) Feel interested in the new challenge and a little nervous at the same time.

b) Feel excited about the higher status and salary that is involved.

c) Feel stressed and anxious about the upcoming changes.

Name or Code: ____

Sex: M

F (circle one) Date: ________________________

Individual Styles Response Form - 12 Vignettes

KEY: A = Autonomy , C = Control , I = Impersonal

1.	**a**	**I**	**2.**	**a**	**A**	**3.**	**a**	**C**
	b	**C**		**b**	**I**		**b**	**I**
	c	**A**		**c**	**C**		**c**	**A**
4.	**a**	**A**	**5.**	**a**	**A**	**6.**	**a**	**I**
	b	**C**		**b**	**I**		**b**	**A**
	c	**I**		**c**	**C**		**c**	**C**
7.	**a**	**C**	**8.**	**a**	**C**	**9.**	**a**	**I**
	b	**A**		**b**	**I**		**b**	**C**
	c	**I**		**c**	**A**		**c**	**A**
10.	**a**	**I**	**11.**	**a**	**C**	**12.**	**a**	**A**
	b	**A**		**b**	**A**		**b**	**C**
	c	**C**		**c**	**I**		**c**	**I**

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